

# THE METALLURGISTS AND CHEMISTS' HANDBOOK

A REFERENCE BOOK OF TABLES AND  
DATA FOR THE STUDENT AND  
METALLURGIST

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## PREFACE TO THE FIRST EDITION

This book is but little more than a collection of tables—those which my own experience and the requests from the readers of the *Engineering and Mining Journal* have led me to believe are most necessary to the chemist and metallurgist. There is no lengthy discussion of processes or apparatus. The field of descriptive metallurgy is at present too crowded by the monumental works of Schnabel, Hofman, Roberts-Austen and others, to admit of further competition. Certain sections will probably be criticized for their brevity, but these treat of those processes where there are no tables of constants, and the matter must either be descriptive or else non-existent.

In the preparation of these tables I have been constantly struck by the divergent values given by different authorities for the same constants. While space has usually prevented my giving the names of the experimenters and the dates of their work, I have attempted to exercise some discrimination in the choice between published values, taking into consideration the experimenter where known, and so far as available, the methods used, and, if I had not the original source, the general character of the book in which his work was transcribed.

Yet, on the theory of probability only, the choice cannot always have been a happy one. Again, apart from any reliability of the figures as I have found or chosen them, several years of sad experience have demonstrated the fallibility of compositors and proofreaders. So for all the unknown errors of fact, of judgment and of type contained herein, I herewith tender apology. And I shall therefore take it as a favor to be advised of any errors which the reader may detect, at the same time asking his indulgence concerning them.

Thanks are due the many publishers who have so kindly allowed copying from their publications—who they are can be seen from the footnote credits through the book. I must also thank the friends who have aided me in its preparation: Dr. Edward Weston, of Elizabeth, N. J., and W. R. Ingalls, H. A. McGraw and Percy E. Barbour, of the *Engineering and Mining Journal*. Mr. McGraw contributed nearly all the data on ore dressing and cyanidation and Mr. Barbour, besides giving some valuable data, checked the page proof from beginning to end. He is doubtless the only man beside the author who will ever read the entire book. And more than all is appreciation due for the many hours of painstaking work by my wife in compiling and checking the various tables, and in reading the proofs.

DONALD M. LIDDELL.

ELIZABETH, N. J.,  
February 11, 1916.



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# METALLURGISTS AND CHEMISTS' HANDBOOK

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## SECTION I MATHEMATICS

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### SYMBOLS

The abbreviations given below will be standard in this book. It has been attempted to make them conform to those recommended by the International Electrotechnical Commission, and the current practice of the best edited chemical, physical, and mathematical publications.

<i>A</i>	ampere; <sup>1</sup> work (the latter also represented by <i>W</i> )
<i>a</i>	acceleration
<i>B</i>	magnetic flux density
<i>B, b</i>	breadth
<i>C</i>	coulombs; electric capacity; Centigrade temperature
<i>D</i>	electrostatic flux density; depth
<i>d</i>	differential
$\gamma$	coefficient of adiabatic expansion, 1.406 approx.
$\Delta$	heat; increment
$\partial$	partial differential
<i>E, e</i>	electromotive force; lumens per sq. cm., foot candles
<i>e</i>	base of Napierian logarithms = 2.718281828459
$\epsilon$	dielectric constant
<i>F</i>	factor of safety; farad <sup>1</sup>
<i>f</i>	frequency; force; coefficient of friction
<i>G</i>	conductance
<i>g</i>	acceleration due to gravity = 981 cm. per sec.
<i>H</i>	magnetic field; henry <sup>1</sup>
<i>H, h</i>	height; head
$\eta$	efficiency
<i>I, i</i>	current; international candle
<i>i</i>	imaginary square root of $-1$ ; in older works, amperes
$\bullet J$	intensity of magnetization; mechanical equivalent of heat, the joule <sup>1</sup>
<i>K</i>	absolute temperature (Kelvin)
$\kappa$	susceptibility
<i>L</i>	self-inductance; lumen-second or-hour
<i>l</i>	length <sup>2</sup>

<sup>1</sup> Recommended by the International Electrotechnical Commission for use after numerical values.

<sup>2</sup> In dimensional equations, use *L, M, T*, for length, mass and time.

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$M$	mutual inductance
$m$	mass <sup>1</sup>
$\mu$	permeability; coefficient of friction
$n$	number of turns in unit of time
$\omega$	angular velocity, $\frac{2\pi}{T}$
$P$	power; pressure
$p$	pressure
$\pi$	ratio of circumference to diameter = 3.1415926535897
$Q$	quantity of electricity
$R$	resistance; gas constant
$r$	radius
$\rho$	resistivity
$S$	reluctance
$\Sigma$	summation
$T$	absolute temperature; thickness; period
$t$	temperature, time, <sup>2</sup> thickness
$\theta, \vartheta$	temperature centigrade
$\Theta$	temperature absolute
$V, v$	velocity, volt <sup>1</sup>
$X$	reactance
$W$	weight; energy; watt <sup>1</sup>
$w$	weight
$\varphi$	phase displacement
$\Phi$	magnetic flux
$Z$	impedance

### Mathematical Symbols

+	plus, positive	$\angle$	angle
-	minus, negative	$\square$	parallelogram
$\pm$	plus or minus	$\square$	square
=	equals or equal to <sup>1</sup>	$\odot$	circle
$\approx$	equivalent to	$\perp$	right angle
$\times$	multiplied by	$\perp^\circ$	perpendicular to
$\div$	divided by	$^\circ$	degree, hour
>	greater than	'	minute, foot
<	less than	"	second, inch
$\propto$	varies as	$\sqrt[n]{a}$	"n"th root
({   ———   }), symbols denoting		$a^n$	"n"th power
numbers enclosed are considered as one expression		$\Sigma$	summation
$\Delta$	triangle	$\sim$	cycle
$\pi$	ratio of circumference to diameter	$\Delta$	increment
log	logarithm	$\int$	integral
log <sub>n</sub>	log to base "n"	$\partial$	partial differential
$a:b::c:d, \frac{a}{b} = \frac{c}{d}$	$a$ is to $b$ as $c$ is to $d$	$\equiv$	identical
		$\doteq$	approaches
		$\infty$	infinity

<sup>1</sup> Recommended by the International Electrotechnical Commission for use after numerical values.

<sup>2</sup> In dimensional equations, use  $L, M, T$ , for length, mass and time.

**Trigonometric Abbreviations**

• sin	sine	tan	tangent
cos	cosine	cot	cotangent
sec	secant	versin	versed sine
csc	cosecant	covers	covered sine
$\sin^{-1}\theta$	angle whose sine is $\theta$	$\sin \theta^{-1}$	$\frac{1}{\sin \theta}$

**The Greek Alphabet**

A, $\alpha$	alpha	I, $\iota$	iota	P, $\rho$	rho
B, $\beta$	beta	K, $\kappa$	kappa	$\Sigma, \varsigma, \sigma$	sigma
$\Gamma, \gamma$	gamma	$\Lambda, \lambda$	lambda	T, $\tau$	tau
$\Delta, \delta$	delta	M, $\mu$	mu	T, $\nu$	upsilon
$\therefore$ E, $\epsilon$	epsilon	N, $\nu$	nu	$\Phi, \phi$	phi
Z, $\zeta$	zeta	$\Xi, \xi$	xi	X, $\chi$	chi
H, $\eta$	eta	O, $\omicron$	omicron	$\Psi, \psi$	psi
$\Theta, \theta, \vartheta$	theta	$\Pi, \pi$	pi	$\Omega, \omega$	omega

**Mathematical Constants**

$e = 2.718281828459045$	$\log_e 10 = 0.434294$
$\pi = \frac{355}{113}$ (approx.).	$e = \frac{299}{110}$ (approx.).
$\pi = 3.14159265358979$	$\log \pi = 0.4971499$
$\sqrt{\pi} = 1.772454$	$\log_e x = 2.302585 \log_{10} x$
$\pi^2 = 9.869605$	$\frac{1}{\pi^2} = 0.1013212$
$\frac{1}{\pi} = 0.3183102$	
$\sqrt{2} = 1.4142136$	$\sqrt[3]{3} = 1.4422509$
$\sqrt[3]{2} = 1.2599210$	$\sqrt{5} = 2.2360680$
$\sqrt[3]{.5} = 0.7937002$	$\sqrt[3]{5} = 1.709976$
$\sqrt{3} = 1.7320508$	

**Temperature Reduction**

The Fahrenheit scale is based on  $212^\circ$  as the boiling point of water at normal pressure,  $32^\circ$  as the freezing point. Its zero was formerly supposed to be the lowest temperature attainable artificially.

The Centigrade (Celsius) scale assumes the freezing point of water as being  $0^\circ$ , the boiling point under normal pressure as  $100^\circ$ .

The Reaumur scale assumes the freezing point of water as  $0^\circ$ , the boiling point of water as  $80^\circ$ .

$$\begin{aligned} \frac{9}{10} \text{ C.}^\circ &= \text{R.}^\circ; \frac{10}{9} \text{ R.}^\circ = \text{C.}^\circ \\ \frac{5}{9} (\text{F.}^\circ - 32) &= \text{C.}^\circ; \frac{9}{5} \text{ C.}^\circ + 32 = \text{F.}^\circ \\ \frac{4}{9} (\text{F.}^\circ - 32) &= \text{R.}^\circ; \frac{9}{4} \text{ R.}^\circ + 32 = \text{F.}^\circ \end{aligned}$$

The equivalent points on the different scales are

$$\begin{aligned} 0.0^\circ \text{ C} &= 0.0^\circ \text{ R.} \\ -40.0^\circ \text{ C} &= -40.0^\circ \text{ F.} \\ -25.6^\circ \text{ R} &= -25.6^\circ \text{ F.} \end{aligned}$$

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## Units of Heat

The British Thermal Unit (B.T.U.) is the quantity of heat required to raise the temperature of 1 lb. of water 1°F., at or near its maximum density (39.1°F.).

The calorie (cal.) is the quantity of heat necessary to raise the temperature of 1 gram of water from 10°C. to 11°C. (sometimes also defined as "from 4°C. to 5°C.," less commonly still, from "0°C. to 1°C.").

The kilogram-calorie (Cal.) is 1000 times the above.

The pound-calorie is the quantity of heat necessary to raise the temperature of 1 lb. of water 1°C. (usually from 4°C. to 5°C.).

1.0 Cal. = 3.968 B.T.U. = 2.2046 lb.-cal.

1.0 B.T.U. = 0.252 Cal. = 778 ft.-lb. = 1054.6 joules (60°F.)

1 lb.-Cal. =  $\frac{2}{5}$  B.T.U. = 0.4536 Cal.

**Latent heat** of a substance is the number of calories required to be absorbed to change 1 gram of the substance from a solid to a liquid or a liquid to a gas, without change of temperature. An equal quantity is given out when the reverse change takes place.

**Specific heat** of a substance is the ratio of the quantities of heat necessary to raise the temperature of equal masses of the substance and of water from the same to the same temperatures.

## \* Scale of Temperatures by Color of Iron<sup>1</sup>

Dark red—hardly visible	970°F.	Orange	2000°F.
Dull red	1300°F.	Yellow	2150°F.
Cherry—dark	1450°F.	White heat	2350°F.
Cherry—red	1650°F.	White welding	2600°F.
Cherry—light	1800°F.	White—dazzling	2800°F.

## Standard Thermometric Points<sup>2</sup>

Ice melts	0.0°C.	Zinc solidifies	419.4°C.
Water boils	100.0°C.	Sulphur boils	444.6°C.
Aniline boils	184.4°C.	Antimony solidifies	630.5°C.
Naphthalene boils	217.9°C.	Sodium chloride	
Tin solidifies	231.9°C.	solidifies	884.0°C.
Benzophenone boils	306.0°C.	Silver solidifies	960.5°C.
Lead solidifies	327.5°C.	Copper solidifies	1083.0°C.

## Weights and Measures

### LINEAR MEASURE—ENGLISH

12 in. = 1 ft.

3 ft. = 1 yd.

5½ yd. or 16½ ft. = 1 rod or perch.

320 rods, 1760 yd., 5280 ft. = 1 mile.

Also a number of miscellaneous units, some of which are obsolete, or obsolescent, others are used by certain trades only.

<sup>1</sup> For tables of melting points, see pp. 262, 302, 555 and 814. For Seger-cone data see p. 565.

<sup>2</sup> According to the National Physical Laboratory.

A point	= $\frac{1}{16}$ in.
A line	= $\frac{1}{32}$ in.
A barleycorn	= $\frac{1}{3}$ in.
A palm	= 3 in.
A hand	= 4 in.
A span	= 9 in.
A cubit	= 18 in.
A military pace	= 30 in.
A link	= $\frac{1}{100}$ chain = 0.66 ft.
A knot (nautical mile)	= 6086 ft.
A fathom	= 6 ft. (United States)
A fathom	= 6.08 ft. (British)
1 ell (English)	= 45 in.
1 ell (Dutch)	= 1.094 yd.
1 bolt	= 40 yd.
A chain	= 4 rods (66 ft.) = 20.11684 meters
A furlong	= $\frac{1}{8}$ mile
A league	= 3 knots
A cable length	= 120 fathoms (United States)
A cable length	= 608 ft. (British)
An International Geographical mile	= $\frac{1}{16}$ at equator = • 24,350.3 ft.
A British nautical mile	= 6,080.4 ft.

### Linear Measure—French<sup>1</sup>

10 millimeters	= 1 centimeter	10 dekameters	= 1 hektometer
10 centimeters	= 1 decimeter	10 hektometers	= 1 kilometer
10 decimeters	= 1 meter	10 kilometers	= 1 myriameter
10 meters	= 1 dekameter		
A micron is $\frac{1}{1000}$ mm.; a millimicron = $\frac{1}{1000}$ micron;			
1 ångström unit = $\frac{1}{10}$ millimicron = $10^{-8}$ cm.			

### Conversion Table, Linear Measure<sup>2</sup>

1 in.	= 2.540005 cm.	1 cm.	= 0.393700 in.
1 ft.	= 0.3048006 m.	1 m.	= 39.37000 in. = 3.28083 ft.
1 yd.	= 0.9144018 m.	1 m.	= 1.09361 yd. = 0.00062 mi.
1 mi.	= 1.609347 km.	1 km.	= 0.62137 mi. = 3280.83 ft.

The old French measures and their equivalents are:

1 toise	= 1.9490366 m.	1 ponce	= 2.706995 cm.
1 pied	= 0.3248394 m.	1 ligne	= 0.225583 cm.
1 toise = 6 pieds = 72 ponces = 864 lignes			

<sup>1</sup> The decimeter, dekameter, hektometer and myriameter are seldom used as compared with the other measures. When the metric system was devised the meter was supposed to be one ten-millionth part of the quadrant of the earth's surface. However, owing to inaccuracies of measurement, this is only approximately true, and the meter must be defined as the length of a standard bar of platinum kept in Paris, when measured at a temperature of zero degrees centigrade.

<sup>2</sup> The foot is defined by United States law as being  $\frac{1200}{3937}$  meters. Therefore in the United States 1 meter = 39.37 in. exactly. The British equivalent is, however, 1 m. = 39.370113 in. Apparently the British inch and the American inch were intended to be equivalent, but are not, though I have never heard of any notice being taken of this fact in commercial transactions. The value 1 meter = 39.37 in. has been used in all equivalents in this book.

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### Square Measure—English

144 sq. in.	= 1 sq. ft.
9 sq. ft.	= 1 sq. yd.
30.25 sq. yd.	} = 1 sq. rod
272.25 sq. ft.	
160 sq. rd. = 10 sq. chains	= 4 roods = 1 acre
640 acres	= 1 sq. mi.
1 morgen (So. Af.)	= 600 sq. Cape roods = 2.11654 acres
A square of flooring or roofing	= 100 sq. ft.
A section of land	= 1 mi. sq. = 640 acres
A township	= 36 sq. mi.
A board foot	= 1 ft. square $\times$ 1 in. thick

### Square Measure—French

100 sq. mm.	= 1 sq. cm.
100 sq. cm.	= 1 sq. dm.
100 sq. dm.	= 1 sq. m. (centar)
100 sq. m.	= 1 sq. dekameter or ar
100 sq. dekameters	= 1 sq. hektometer (hektar)
100 sq. hektometers	= 1 sq. kilometer

### Conversion Table, Square Measure

1 centar (1 sq. m.)	= 1550 sq. in.	= 10.764 sq. ft.
1 ar	= 119.6 sq. yd.	
1 hectar	= 2.47104 acres.	1 acre = 0.40469 hektar
1 sq. cm.	= .15500 sq. in.	1 sq. in. = 6.4515898 sq. cm.
1 sq. meter	= 10.76387 sq. ft.	1 sq. ft. = 0.092903 sq. m.
1 sq. km.	= 0.3861 sq. mi.	1 sq. mi. = 2.589998 sq. km.

### Cubic Measure—English<sup>1</sup>

1728 cu. in.	= 1 cu. ft.
27 cu. ft.	= 1 cu. yd.
128 cu. ft.	= 1 cord
50 cu. ft. of square timber	= 1 load
40 cu. ft. of unhewn timber	= 1 load
A board foot	= 1 ft. square $\times$ 1 in. thick

### Weight—English

Avoirdupois	
16 drams (dr.)	= 1 ounce (oz.)
16 oz.	= 1 pound (lb.)
100 lb.	= 1 hundred-weight (cwt.) <sup>2</sup>
20 cwt.	= 1 ton
Troy	
24 grains	= 1 pennyweight (dwt.)
20 dwt.	= 1 oz. Tr.
12 oz. Tr.	= 1 lb. Tr.

<sup>1</sup> For French cubic equivalents see under "Measures of Capacity," p. 9.  
<sup>2</sup> But in England, a hundred weight is understood as 112 lb. = 8 stone.



The Avoirdupois pound = 7000 grains = 14.5833 oz. Tr.  
 The Troy pound = 5760 grains = 13.1657 oz. Avoir.  
 The Avoirdupois ounce = 437.5 grains = 0.9115 oz. Tr.

1 ton = 29,166.66 oz. Tr.

1 ton = 0.89287 long ton

1 long ton = 1.12 short tons = 2240 lb.

(Troy weight is used in weighing gold, silver, platinum, etc.  
 In weighing precious stones the metric carat = 200 mg., is now used.)

1 barrel of flour = 8 sacks = 196 lb.

1 barrel of pork = 200 lb.

1 barrel of cement = 4 sacks = 376 lb.

1 stone = 14 lb.

### Weights—French

10 milligrams = 1 centigram      10 centigrams = 1 decigram

10 decigrams = 1 gram              10 grams = 1 dekagram

10 dekagrams = 1 hectogram      10 hectograms = 1 kilogram<sup>1</sup>

100 kilograms = 1 metric quintal

1000 kilograms = 1 metric ton (tonne) or millier

### Conversion Table, Weight

1 oz. avoirdupois = 28.349527 grams

1 lb. avoirdupois = 453.5924277 grams

1 ton = 907.1848554 kg.

1 gram = 0.035274 oz. avoirdupois = 0.00220462 lb.

1 kg. = 35.27396 oz. avoirdupois = 2.204622341 lb.

1 metric ton = 1.102311 tons = 0.9842 long tons

1 grain = 64.7989182 mg.

1 dwt. = 1.55517 g.

1 oz. Troy = 31.1035 g.

1 lb. Troy = 0.37324 kg.

1 gram = 15.4324 gr. = 0.64301 dwt.<sup>2</sup>

1 gram = 0.64301 dwt. = 0.03215 oz. Tr.<sup>1</sup>

1 kg. = 32.15074 oz. Tr. = 2.67923 lb. Tr.

The *libra* used in Spain, Portugal and Spanish America differs slightly from the U. S. pound, ranging from 1.012 in Portugal and Brazil to 1.016 in Cuba and Porto Rico.

**The Assay Ton.**—A weight used by assayer such that 1 ton (2000 lb.): 1 oz. Tr.: 1 A.T.: 1 mg.; i.e., if the assayer weighs

<sup>1</sup> When the metric system was devised, it was intended that 1 gram should equal the mass of 1 cubic centimeter of water at its greatest density (4°C.) This relation does not exactly hold, and it is necessary to define the gram as the one-thousandth part of a standard mass of platinum kept in Paris. At 4°C. the mass of 1 cc. of water differs so slightly from unity that for nearly all calculations no correction is necessary. A liter was intended to be equal to 1000 cc. but was defined as the volume occupied by a kilogram of water at 4°C. and 760 mm. pressure. It is therefore equivalent to 1000.027 cc. (de Lépina, Bessiot and Buisson.)

<sup>2</sup> A U. S. half dollar weighs 12.5 g.

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out assay tons, each milligram of metal recovered represents 1 Troy oz.

$$1 \text{ A.T.} = 29.16667 \text{ grams}$$

On the English system, ton of 2240 lb.

$$1 \text{ A.T.} = 32.66667 \text{ grams}$$

Apothecaries Weight		Apothecaries Measure	
20 grains	= 1 scruple (℥)	60 minims (℥)	= 1 dram =
3 ℥	= 1 dram (℥)		0.22559 cu. in.
8 ℥	= 1 ounce (℥)	8 drams	= 1 fluid ounce
12 ℥	= 1 lb. Tr.	16 fl. oz.	= 1 pt.

The apothecaries grain is equal to the Troy grain; the scruple to  $\frac{1}{4}$  of the pennyweight.

1 gr.	= 64.7989182 mg.	1 ℥	= 1295.98 mg.
1 ℥	= 3887.94 mg.	1 fl. oz.	= 29.5729 milliliters
	1 milliliter (1 cc.)		= 0.3381 fl. oz.

### Measures of Capacity—English

Dry		Liquid	
2 pt.	= 1 qt.	4 gills	= 1 pt.
8 qt.	= 1 peck	2 pt.	= 1 qt.
4 pk.	= 1 bushel (2150.42 cu. in.)	4 qt.	= 1 gal. (231 cu. in.)
31 $\frac{1}{2}$ gal.	= 1 barrel (bbl.) U. S.;		
2 bbl.	= 1 hogshead (hhd.) double cask		
2 hhd.	= 1 pipe		
42 gal.	= 1 bbl. (Standard Oil Co.), formerly a tierce		
84 gal. (2 tierces)	= 1 puncheon		
	An Imperial gallon contains	277.408 cu. in. <sup>1</sup>	
	An Imperial bushel contains	2219.36 cu. in. <sup>1</sup>	
	A quarter contains	8 Imperial bu.	

NOTE.—It can be seen that the dry quart contains  $67\frac{1}{2}$  cu. in., while the liquid quart contains only  $57\frac{3}{4}$  cu. in. There is therefore no royal road to reducing dry measures to wet equivalents, though the ratio is about 1:1 $\frac{1}{6}$  (1.16364).

1 Imperial gal.	= 1.20095 U. S. gal.
1 U. S. gal.	= 0.83267 Imp. gal.
1 Imp. bu.	= 1.03151 U. S. bu.
1 U. S. bu.	= 0.96945 Imp. bu.
1 gal. (ale or beer)	= 1.2208 U. S. gal.
1 muid (Cape)	= 3 $\frac{1}{2}$ Imp. bu. (approx.)

<sup>1</sup> The Imperial gallon is defined as containing ten Imperial standard pounds weight of distilled water weighed in air against brass weights with the water and air at the temperature of 62°F., and the barometer at 30 in. While the Standards Department of the Board of Trade accepts 277.420 cu. in. as the proper conversion value, it has no statutory sanction or legal authority. The Imperial bushel is 8 Imp. gal. Nowhere in English law is it defined in cubic inches. The Board of Trade accepts the value given where a knowledge of cubic contents is necessary. An Imperial gallon is consequently 4.5459631 liters.

Grains per U. S. gal.	$\times 17.138$	= parts per million
Grains per Imp. gal.	$\times 14.285$	= parts per million
Parts per million	$\times 0.0583$	= grains per U. S. gal.
Parts per million	$\times 0.700$	= grains per Imp. gal.

### Measures of Capacity—French

1000 cu. mm.	= 1 cc.
1000 cc.	= 1 cu. dm. (liter)
1000 cu. dm.	= 1 cu. m.

In measuring wood, the cubic meter is called a *stér.*

10 milliliters	= 1 centiliter
10 centiliters	= 1 deciliter
10 deciliters	= 1 liter
10 liters	= 1 dekaliter
10 dekaliters	= 1 hectoliter
10 hectoliters	= 1 kiloliter

### Conversion Tables, Cubic Measure

1 cu. in.	= 16.3870253 cc.
1 cc.	= 0.06102338 cu. in. = 0.0000353 cu. ft.
1 cu. ft.	= 0.02831677 cu. m. = 28.3160 liters
1 cu. m.	= 35.31445 cu. ft. = 1.30794 cu. yd.
1 cu. yd.	= 0.764559 cu. m.

### Liquid Equivalents

fl. oz.	= 29.5729 milliliters
1 milliliter	= .03381 fl. oz. = 0.061025 cu. in.
1 gill	= 1.1829 deciliters
1 deciliter	= 0.8454 gills
1 quart	= 0.94633 liters
1 liter	= 1.0567 quarts
1 U. S. gal.	= 3.785332 liters
1 dekaliter	= 2.6418 gal.

### Dry Equivalents

1 pt.	= 0.550599 liters
1 deciliter	= 0.18162 pt.
1 qt.	= 1.10129 liters
1 liter	= 0.90810 quarts
1 pk.	= 0.08810 hectoliter
1 hectoliter	= 2.8378 bu.
1 bu. (U. S.)	= 0.35238329 hectoliter
1 bu. (Imp.)	= 0.353677048
1 kiloliter	= 1.3079 cu. yd.

### Circular and Angular Measure

60 sec. (")	= 1 minute (')
60 min. (')	= 1 degree (°)
360 deg. (°)	= 1 circumference

In the higher mathematics another unit is used:

$2\pi$ radians	= 1 circumference
$\therefore 1$ radian	= $57.2957795^\circ = 57^\circ 17' 44.806''$

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## Time

60 sec. = 1 min.; 60 min. = 1 hr.; 24 hr. = 1 day  
 365.242218 solar days = 1 year  
 29 days 12 hr. 44 min. = 1 lunar month

A seconds pendulum = 39.138 in. = 0.9958 meters in the latitude of New York at sea level.

The period of a pendulum is  $\pi\sqrt{\frac{l}{g}}$ , where  $l$  is length, and  $g$  the acceleration due to gravity.

## Miscellaneous

20 units = 1 score                      24 sheets = 1 quire  
 12 units = 1 dozen                    20 quires = 1 ream  
 12 dozen = 1 gross                    2 reams = 1 bundle  
 12 gross = 1 great gross            5 bundles = 1 bale  
 1 atmosphere = 14.7 lb. per sq. in. = 29.922 in. of mercury =  
 33.9 ft. of water

## C.G.S. Units

The unit of force is the dyne. It is that force which applied to a mass of one gram will give it an acceleration of one centimeter in one second.

The unit of work is the erg. This is the work done by one dyne acting through a distance of one centimeter. The joule =  $10^7$  ergs.

A caloric is the heat necessary to raise the temperature of 1 gram of water from 0°C. to 1°C.<sup>1</sup>

A great caloric (Caloric) is the heat necessary to raise the temperature of 1 kg. of water from 0°C. to 1°C.<sup>1</sup>

Unit	Erg	Joule	Kilogram-meter (g. = 980.665)	Calorie	Small caloric
Erg. . . . .	1	$10^{-7}$	$\frac{1}{980.665}$	$\frac{2.39011}{10^{-4}}$	$\frac{2.39011}{10^{-8}}$
Joule . . . . .	$10^7$	1	0.10197	$\frac{2.39011}{10^{-4}}$	$\frac{2.39011}{10^{-1}}$
Kilogram-meter (g. = 980.665)	$\frac{980.665}{10^3}$	$\frac{9.807}{10^3}$	1	$\frac{2.3446}{10^{-3}}$	2.3446
Calorie..	$418.6 \times 10^3$	4186	426.5	1	1000

The unit magnetic mass or pole is such that placed at a distance of one centimeter from an identical mass, it exercises a repulsion equal to 1 dyne.

The permeability is the ratio of flux density to magnetic intensity.

The unit of electric current in the C.G.S. system is a current that exerts a force of one dyne on a unit magnetic pole placed at the center of an arc of the circuit, 1 cm. long, and 1 cm. radius. The practical unit is the ampere (see below), which is one-tenth the C.G.S. unit.

<sup>1</sup> Sometimes also defined at 4 to 5°C; by a few writers as from 10 to 11°C.

The C.G.S. unit of quantity is the quantity which in one second is conveyed by a C.G.S. unit of current. The practical unit is the coulomb, the quantity of current passing per second, in a current carrying one ampere. It is one-tenth the C.G.S. unit.

The C.G.S. unit of potential difference or electromotive force is the potential difference which exists between two points of a conductor conveying a unit current when one erg of work is done per second. The practical unit is the volt (see below) =  $10^9 \times$  the C.G.S. unit.

C.G.S. unit of resistance is the resistance possessed by a conductor through which a unit e.m.f. causes a unit current to flow. The practical unit is the ohm (see below) =  $10^9 \times$  the C.G.S. unit.

The C.G.S. unit of capacity of a condenser is that capacity which gives a unit potential difference between the coatings when either coating has a unit quantity of electricity. The farad is the practical unit and equals  $10^{-9}$  times the C.G.S. unit.

A Gauss is the unit of field strength, the intensity of field which acts on a unit pole with a force of one dyne. A unit magnetic pole has  $4\pi$  lines of force proceeding from it. It is equal to gilberts per centimeter length. Gauss = maxwells  $\div$  area.

A Maxwell is the unit of magnetic flux, the amount of magnetism passing through every square centimeter of a field of unit density. The weber is 1,000,000 maxwells. If a conductor cuts a magnetic field so that one volt is induced, 100,000,000 maxwells are cut per second.

A Gilbert is the unit of magneto-motive force, the amount produced by  $\frac{10}{4\pi} = 0.7958$  ampere turns. The m.m.f. of a coil is 1.2566 times the ampere turns.  $\phi$  = flux in maxwells.

Reluctance is that quantity in a magnetic circuit which limits the flux under a given m.m.f. It corresponds to the resistance in the electric circuit.

The Oersted is the unit of magnetic reluctance, it is the reluctance of a cubic centimeter of an air-pump vacuum.

Inductance is the property of a circuit which opposes any change in current flowing by inducing a counter-electromotive force in the circuit at the time the current is changing. The practical unit is the henry (see below) =  $10^9 \times$  the C.G.S. unit.

## PRACTICAL ELECTRICAL UNITS

**Ohm**—unit of resistance. The International Ohm<sup>1</sup> is the resistance offered to an unvarying electric current by a column

<sup>1</sup> The true ohm (=  $10^9$  electromagnetic C.G.S. units) is apparently the resistance of 106.29 cm. of mercury 1 sq. mm. in section. The 1884 legal ohm = 0.9972 int'l. ohms. The B.A. ohm = 0.9866 int'l. ohm.

A joule is almost equal to the energy expended in one second by an international ampere in an international ohm.

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1 chih (China)	= 1.049867 ft.
1 cho (Japan)	= 357 916 ft.
1 cuadra (Argentina)	= 4.2 acres
1 dcssiatine (Russia)	= 2.6997 acres
1 dhraa (Morocco)	= 22 48 in.
1 doli (Russia)	= 0.685 grains
1 duime (Russia)	= 1 in.
1 fanega (Argentina)	= 3.89 bu.
1 fen (China)	= 0 12598 in.
1 fen (sq.) (China)	= 0.015182 acres
1 fod (Denmark)	= 1 03 ft.
1 frasco (Argentina)	= 2.5096 quarts
1 funt (Russia)	= 0.9028 lb. = 409 grains
1 fuss (Austria)	= 1.0366 ft.
1 go (Japan)	= 1.270506 gill liquid = 0.0198517 peck dry
1 hao (China)	= 2 5715 ft.
1 sq. hao (China)	= 0 00015181 acres
1 jo (Japan)	= 3 31404 yd.
1 ken (Japan)	= 1 983427 yd.
1 kin (Japan)	= 1 32277 lb. Avoir.
1 koku (Japan)	= 39 7033 gal. liquid = 4 96291 bu. dry
1 kwan (Japan)	= 8 26733 lb. Avoir.
1 kup (Siam)	= 10 in.
1 legua (Brazil)	= 4 102 miles
1 li (China)	= 0 012598 in.
1 liang (China)	= 1 31561 oz. Avoir.
1 lima (Russia)	= 0 1 in.
1 lyi (China)	= 0 0015181 acres
1 manzana (Costa Rica)	= 1 625 acres
1 marc (Belvia)	= 0 507 lb
1 maund (Bengal)	= 82 2855 lb.
1 maund (Bombay)	= 28 lb.
1 maund (Madras)	= 25 lb.
1 meou (China)	= 0 15182 acres
1 mil (Denmark)	= 4.68 mi.
1 mulla (Nicaragua, Honduras)	= 1.1493 miles
1 momme (Japan)	= 2.4123045 dwt.
1 morgen (Cape)	= 2.11654 acres
1 muid (Cape)	= 3½ Imp. bu approx.
1 pie (Argentina)	= 0 9478 ft.
1 pie (Spain)	= 0 91407 ft.
1 pikul (Borneo, Java)	= 135.6354 lb.
1 pikul (China, Str Sett.)	= 133½ lb.
1 pikul (Japan)	= 132 277 lb.
1 pikul (P. I.)	= 139 485 lb.
1 pipa (Brazil)	= 1.648 quarts
1 pood (Russia)	= 36 1128 lb.
1 pulgada (Argentina)	= 0 947 in.
1 quintal (Argentina)	= 101.28 lb.
1 quintal (Bolivia, Chile, Colombia, Domin. Rep., Spain)	= 101.4 lb.
1 quintal (Brazil)	= 129 526 lb.
1 quintal (Costa Rica)	= 101.465 lb.
1 quintal (Syria, Turkey)	= 125 lb.
1 ri (Japan)	= 2 440338 mi.
1 ri (marine) (Japan)	= 1.1506873 mi.
1 rode (Denmark)	= 12.36 ft.
1 saashen (Russia)	= 7 ft.
1 shaku (Japan)	= 7 lb.
1 sheng (China)	= 11 9305424 in.
1 sho (Japan)	= 2 7354 liq. gal.
1 sun (Japan)	= 1.5881325 qt liquid = 0 1985166 pecks dry
1 tan (Japan)	= 1.1930542 in.
1 teh'e (China)	= 0.24507 acre
1 tchetvert (Russia)	= 12.598 in.
1 to (Japan)	= 117,600 sq. ft.
1 ts'onen (China)	= 3.9703313 gal. liquid = 1.2598 in.

1 tsubo (Japan)	= 3.953829 sq. yd.
1 vara (Argentine)	= 34.1208 in.
1 vara (Brazilian)	= 1.215 yd.
1 vara (Bolivian)	= 0.927 yd.
1 vedro (Russia)	= 300 2 cu. in.
1 verchok (Russia)	= 1.75 in.
1 verst (Russia)	= 3500 ft.
1 zar (Persia)	= 40.9 in.
1 zolotnik (Russia)	= 658 grains

### UNITED STATES AND FOREIGN MONEY

(The following figures are based on the gold standard only and do not include exchange.)

1 oz. of gold = \$20 67183 = £4 24773 = £4 4s. 11½d.	
Argentina (gold)	1 peso = \$0.9648 = 100 centavos
Argentina (paper)	1 peso = 0.4246 = 100 centavos
Austria	1 schilling = 0.1407 = 100 heller
Belgium	1 belga = 0.13904 = 100 centimes
Bolivia	1 boliviano = 0.3893 = 100 centavos
Brazil	1 milreis = 0.5463 = 1000 reis
Ceylon	1 rupee = 0.32143 = 100 cents
Czechoslovakia	1 crown = 0.203
Chile	1 peso = 0.12165 = 100 centavos
China	1 Haikwan tael = 1½ oz. avoirdupois of silver = 10 mace
Columbian Rep'b.	1 peso = 0.9733 = 100 centavos
Costa Rica	1 colon = 0.4654 = 100 centavos
Denmark	1 krone = 0.268 = 100 ore
Ecuador	1 sucre = 0.4867 = 100 centavos
Egypt	1 pound (££) = 4.943 = 100 piastres = 1000 milliemmes
Finland	1 finmark = 0.025185
France	1 franc = 0.0395 = 100 centimes
Germany	1 mark = 0.238 = 100 pfennig
Great Britain	1 pound (£) = 4.8665 = 20 shillings = 240 pence¹
Greece	1 drachma = 0.193 = 100 lepta
Guatemala	1 peso = 0.965 = 100 centavos
Haiti	1 gourde = 1.00 = 100 centimes
Holland	1 florin = 0.402
Honduras	1 peso = 0.3979 = 100 centavos
Hongkong	1 dollar = 0.463 = 100 cents = 1000 cash
Hungary	1 pengo = 0.1749 = 100 filler
India	1 rupee (Rs.) = 0.365 = 16 annas = 192 pies²
Italy	1 lira = 0.052631 = 100 centesimos
Japan	1 yen = 0.498 = 100 sen = 1000 rin
Mexico	1 peso = 0.498 = 100 centavos
Netherlands	1 guilder = 0.402 = 100 cents
Nicaragua	1 peso = 0.965 = 100 centavos
Norway	1 krone = 0.268 = 100 ore
Panama	1 balboa = 1.00 = 2 silver pesos = 200 centesimos
Paraguay	1 peso = 0.04 = 100 centavos
Persia	1 kram = 0.193 = 100 shahi
Peru	1 libra (£P) = 4.8665 = 10 dinero = 100 centavos
Philippine Is.	1 peso = 0.50 = 100 centavos
Poland	1 zloty = 0.1122
Portugal	1 escudo = 1.0805 = 1000 reis
Roumania	1 leu = 0.193 = 100 bani
Russia	1 ruble = 0.515 = 100 kopecks
Russia (Soviet)	1 chervonetz = 5.14
Salvador	1 peso = 0.3978 = 100 centavos
Spain	1 peseta = 0.193 = 100 centesimos
Straits Settlements	1 dollar = 0.5677 = 100 cents
Sweden	1 krona = 0.268 = 100 ore
Turkey	1 pound (£T) = 4.40 = 100 piasters = 4000 paras
Uruguay	1 peso = 1.0342 = 100 centavos
Venezuela	1 bolivar = 0.1930 = 100 centimos
Yugoslavia	1 dinar = 0.193

¹ 5 shillings = 1 crown; 21 sh. = 1 guinea; 4 farthings = 1 penny (d.)

² A lakh = 100,000 rupees; a crore = 10,000,000 rupees.

FINENESS OF COINAGE<sup>1</sup>

Country	Gold coin	Silver coin	Country	Gold coin	Silver coin
Abyssinia.....		835	Honduras.....		900
Argentina.....	900.0	900	Honduras (British).....		925
Austria-Hungary.....	900.0	900,835	Hongkong.....		800
Belgium.....	900.0	900,835	India.....	916.6	916.6
Bolivia.....		900	Italy.....	900.0	900,835
Brazil.....	916.6	916.6	Japan.....	900.0	800
Bulgaria.....	900.0	900,835	Mauritius.....		800
Canada.....		925	Mexico.....		902.7,800
Ceylon.....		800	Morocco.....		900,835
Chile.....	916.6	500	Newfoundland.....	916.6	925
China.....		900,866,820	Nicaragua.....		800
Colombia.....	900.0	900,835	Norway.....	900.0	800,600,400
Congo.....	900.0	900,835	Panama.....	900.0	900
Corea.....	900.0	800	Paraguay.....		900
Costa Rica.....	900.0	900	Persia.....	900.0	900
Crete.....	900.0	900,835	Peru.....	916.6	900
Curacao.....		640	Portugal.....	916.6	916.6
Cyprus.....		925	Roumania.....	900.0	900,835
Denmark.....	900.0	800,600,400	Russia.....	900.0	900,500
Dominica.....		900,835	Salvador.....	900.0	900,835
Dutch East Indies.....		720	Sorvia.....	900.0	900,835
Ecuador.....	900.0	900	Siam.....		900
Egypt.....	875.0	833.3	South Africa.....	916.6	925
Finland.....	900.0	868,750	Spain.....	900.0	900,835
France.....	900.0	900,835	Sweden.....	900.0	800,600,400
Germany.....	900.0	900	Straits Settlements.....		900,800
Great Britain.....	916.0	925	Switzerland.....	900.0	900,835
Greece.....	900.0	900,835	Turkey.....	916.6	830
Guatemala.....	900.0	900,835	United States.....	900.0	900
Hayti.....	900.0	900,835	Uruguay.....		900
Holland.....	900.0	945,640	Venezuela.....	900.0	900,835

## • ALGEBRA

## Powers and Roots

According to the binomial theorem

$$\begin{aligned}
 (a + b)^K &= a^K + K a^{K-1} b + \frac{K(K-1)}{1 \cdot 2} a^{K-2} b^2 + \\
 &\frac{K(K-1)(K-2)}{1 \cdot 2 \cdot 3} a^{K-3} b^3 + \dots + \frac{K(K-1) \dots 2}{1 \cdot 2 \cdot 3 \dots (K-1)} a b^{K-1} + b^K
 \end{aligned}$$

This formula will serve for the solution of any power whatever; and will, in general, serve to indicate the process of the extraction of roots. However, for all practical work on roots and powers, use the table of logarithms on p. 42.

$$\log a^K = K \log a$$

$$\log \sqrt[k]{a} = \frac{\log a}{k}$$

<sup>1</sup> T. K. Rose, "Precious Metals."



### Permutation, Choice and Chance

\*The number of different arrangements (or permutations) of  $n$  different things taken altogether is factorial  $n$ .

$$(n! \text{ or } \underline{n} = n(n-1)(n-2) \cdots 3 \times 2 \times 1)$$

The number of different selections (or combinations) of  $n$  different things taken  $r$  at a time is:

$$\frac{n(n-1)(n-2) \cdots (n-r+1)}{r!}$$

The number of selections of  $n$  things taken  $r$  at a time is the same as the number of selections of  $n$  things taken  $n-r$  at a time.

The number of selection of  $n$  things taken  $r$  at a time is greatest when: If  $n$  is an odd number,

$$r = \frac{n-1}{2}$$

if  $n$  is an even number

$$r = \frac{n}{2}$$

The chance of an event happening is expressed by the fraction of which the numerator is the number of favorable ways, and the denominator the whole number of ways, favorable and unfavorable.

If there are several events of which one, and only one can happen, the chance that one will happen is the sum of the respective chances of happening

### Progression

The chief "progressions" are arithmetical, geometrical, and harmonic. They are series of numbers in which a common law connects the successive terms.

**Arithmetical progression** in a series of numbers consists in a constant difference between the successive terms, as

$$1, 3, 5, 7, 9, \dots$$

Let  $a$  = first term;  $l$  = last term;  $d$  = the common difference;  $n$  = the number of terms;  $s$  = the sum of the terms.

$$l = a + (n-1)d = \frac{2s}{n} - a = \frac{s}{n} + \frac{(n-1)d}{2} = -\frac{1}{2}d \pm \sqrt{2ds + \left(a - \frac{d}{2}\right)^2}$$

$$s = \frac{n}{2}[2a + (n-1)d] = \frac{n}{2}(l + a) = \frac{n}{2}\left[2l - (n-1)d\right] = \frac{l + a}{2} \left(\frac{d + l - a}{d}\right)$$

$$a = l - (n-1)d = \frac{2s}{n} - l = \frac{s}{n} - \frac{(n-1)d}{2} = \frac{1}{2}d \pm \sqrt{\left(l + \frac{d}{2}\right)^2 - 2ds}$$

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$$d = \frac{l-a}{n-1} = \frac{2(s-an)}{n(n-1)} = \frac{l^2 - a^2}{2s - l - a} = \frac{2(nl-s)}{n(n-l)}$$

$$n = \frac{l-a}{d} + 1 = \frac{2s}{l+a} = \frac{d-2a \pm \sqrt{(2a-d)^2 + 8ds}}{2d} =$$

$$\frac{2l+d \pm \sqrt{(2l+d)^2 - 8ds}}{2d}$$

**Geometrical progression** in a series of numbers consists in a constant ratio existing between the successive terms, as

$$4, 8, 16, 32, \dots$$

Let  $a$  = first term;  $l$  = last term;  $m$  = any (middle) term;  
 $s$  = sum;  $r$  = ratio or constant multiplier.

$$l = ar^{n-1} = \frac{a + (r-1)s}{r} = \frac{(r-1)sr^{n-1}}{r^n - 1}$$

$$m = ar^{m-1}$$

$$s = \frac{a(r^n - 1)}{r - 1} = \frac{rl - a}{r - 1} = \frac{\frac{n-1}{n} \sqrt[l]{l^n} - \frac{n-1}{n} \sqrt[a]{a^n}}{\frac{n-1}{n} \sqrt[l]{l} - \frac{n-1}{n} \sqrt[a]{a}} = \frac{l^n - a^n}{r^n - a^n}$$

$$a = \frac{l}{r^{n-1}} = \frac{(r-1)s}{r^n - 1} = rl - (r-1)s$$

$$r = \frac{\frac{n-1}{n} \sqrt[l]{l}}{\frac{n-1}{n} \sqrt[a]{a}} = \frac{s-a}{s-l}$$

$$r^n - \frac{s}{a}r + \frac{s-a}{a} = r^n - \frac{s}{s-l}r^{n-1} + \frac{l}{s-l} = 0$$

**Harmonic series** is one in which the numbers are the reciprocals of those forming an arithmetical progression. Such series are of small practical value, and such questions as arise in them, when solvable, are best answered by inverting the series, and solving as a problem in arithmetical progression. In ancient times a fictitious importance was attached to them owing to the fact that a series of rods of uniform cross-section having lengths in harmonic progression forms a musical scale, hence the name.

## INTEREST, ANNUITIES, SINKING FUNDS

### Simple Interest

If the principal be represented by	$P$
the interest on \$1 for one year by	$r$
the amount of \$1 for one year by	$R$
the number of years by	$n$
the amount of $P$ after $n$ years by	$A$

$$\text{Then } R = 1 + r$$

$$\text{Simple interest on } P \text{ for one year} = Pr$$

$$\text{Amount of } P \text{ for one year} = PR$$

$$\text{Simple interest on } P \text{ for } n \text{ years} = Pnr$$

$$\text{Amount } P \text{ for } n \text{ years} = P(1 + nr)$$

that is

$$A = P(1 + nr)$$

When any three of the quantities  $A$ ,  $P$ ,  $n$ ,  $r$ , are given, the fourth may be found from this last equation.

Since  $P$  will in  $n$  years at  $r$  interest amount to  $A$ ,  $P$  may be considered equivalent in value to  $A$  at the end of  $n$  years; in other words,  $P$  is the "present worth" of  $A$ .

### Compound Interest

When compound interest is reckoned payable annually.  
The amount of  $P$  dollars in

$$\begin{aligned} 1 \text{ year is } P(1 + r) &= PR \\ 2 \text{ years is } PR(1 + r) &= PR^2 \\ n \text{ years} &= PR^n \end{aligned}$$

$$\text{or } A = PR^n \text{ or } P = \frac{A}{R^n}$$

When compound interest is reckoned semi-annually.  
The amount of  $P$  dollars in

$$\begin{aligned} \frac{1}{2} \text{ year is } P\left(1 + \frac{r}{2}\right) \\ 1 \text{ year is } P\left(1 + \frac{r}{2}\right)^2 \\ n \text{ years, } A = P\left(1 + \frac{r}{2}\right)^{2n} \end{aligned}$$

When the interest is payable quarterly

$$A = P\left(1 + \frac{r}{4}\right)^{4n}$$

When the interest is payable monthly

$$A = P\left(1 + \frac{r}{12}\right)^{12n}$$

And when the interest is payable  $q$  times a year

$$A = P\left(1 + \frac{r}{q}\right)^{qn}$$

### Sinking Funds

If the sum set apart at the end of each year to be put at compound interest be represented by  $S$ , then, the sum at the end of the

$$\begin{aligned} \text{first year} &= S \\ \text{second year} &= S + SR \\ \text{third year} &= S + SR + SR^2 \\ n\text{th year} &= S + SR + SR^2 \dots SR^{n-1} \\ \therefore AR &= S + SR + SR^2 \dots + SR^{n-1} + SR^n \\ \therefore AR - A &= SR^n - S \\ \therefore A &= \frac{S(R^n - 1)}{R - 1} = S \frac{(R^n - 1)}{r} \end{aligned}$$

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COMPOUND INTEREST AND DISCOUNT TABLES. *Continued.*

Years	Four per cent.				Five per cent.			
	Am't of \$1 in n yrs.	Present val. of \$1 due in n yrs.	Am't of \$1 per annum in n yrs.	Present val. of \$1 annuity for n yrs.	Am't of \$1 in n yrs.	Present val. of \$1 due in n yrs.	Am't of \$1 per annum in n yrs.	Present val. of \$1 annuity for n yrs.
1	\$1.040	.9615	1.04	1.000	\$1.050	.9524	1.05	1.000
2	1.082	.9246	2.12	1.962	1.103	.9070	2.15	1.952
3	1.125	.8890	3.25	2.886	1.158	.8638	3.31	2.859
4	1.170	.8548	4.42	3.775	1.216	.8227	4.53	3.723
5	1.217	.8219	5.63	4.630	1.276	.7855	5.80	4.546
6	1.265	.7903	6.90	5.452	1.340	.7462	7.14	5.329
7	1.316	.7599	8.21	6.242	1.407	.7107	8.55	6.076
8	1.369	.7307	9.58	7.002	1.477	.6768	10.03	6.786
9	1.423	.7026	11.01	7.733	1.551	.6446	11.58	7.463
10	1.480	.6756	12.49	8.435	1.629	.6139	13.21	8.108
11	1.539	.6496	14.03	9.111	1.710	.5847	14.92	8.722
12	1.601	.6246	15.63	9.760	1.796	.5568	16.71	9.306
13	1.665	.6006	17.29	10.385	1.886	.5303	18.60	9.863
14	1.732	.5775	19.02	10.986	1.980	.5051	20.58	10.394
15	1.801	.5553	20.82	11.563	2.079	.4810	22.66	10.890
16	1.873	.5339	22.76	12.118	2.183	.4581	24.84	11.380
17	1.948	.5134	24.65	12.652	2.292	.4363	27.13	11.838
18	2.026	.4936	26.67	13.166	2.407	.4155	29.54	12.274
19	2.107	.4746	28.78	13.659	2.527	.3957	32.07	12.690
20	2.191	.4564	30.97	14.134	2.653	.3769	34.72	13.085
21	2.279	.4388	33.25	14.590	2.786	.3589	37.51	13.462
22	2.370	.4220	35.62	15.029	2.925	.3419	40.43	13.821
23	2.465	.4057	38.08	15.451	3.072	.3256	43.50	14.163
24	2.563	.3901	40.65	15.857	3.225	.3101	46.73	14.489
25	2.666	.3751	43.31	16.247	3.386	.2953	50.11	14.799
26	2.772	.3607	46.08	16.622	3.556	.2812	53.67	15.094
27	2.883	.3468	48.97	16.983	3.733	.2678	57.40	15.375
28	2.999	.3335	51.97	17.330	3.920	.2551	61.32	15.643
29	3.119	.3207	55.08	17.663	4.116	.2429	65.44	15.898
30	3.243	.3083	58.33	17.984	4.322	.2314	69.76	16.141
31	3.373	.2965	61.70	18.292	4.538	.2204	74.30	16.372
32	3.508	.2851	65.21	18.588	4.765	.2099	79.06	16.593
33	3.648	.2741	68.86	18.874	5.003	.1999	84.07	16.803
34	3.794	.2636	72.65	19.148	5.253	.1904	89.32	17.003
35	3.946	.2534	76.60	19.411	5.516	.1813	94.84	17.193
36	4.104	.2437	80.70	19.665	5.792	.1727	100.63	17.374
37	4.268	.2343	84.97	19.908	6.081	.1644	106.71	17.547
38	4.439	.2253	89.41	20.143	6.385	.1566	113.10	17.711
39	4.616	.2166	94.03	20.368	6.705	.1491	119.80	17.868
40	4.801	.2083	98.83	20.584	7.040	.1420	126.84	18.017
41	4.983	.2003	103.82	20.793	7.392	.1353	134.23	18.159
42	5.193	.1926	109.01	20.993	7.762	.1288	141.99	18.294
43	5.400	.1852	114.41	21.186	8.150	.1227	150.14	18.423
44	5.617	.1781	120.03	21.371	8.557	.1169	158.70	18.546
45	5.841	.1712	125.87	21.549	8.985	.1113	167.69	18.663
46	6.075	.1646	131.95	21.720	9.434	.1060	177.12	18.774
47	6.318	.1583	138.26	21.885	9.906	.1009	187.03	18.880
48	6.571	.1522	144.83	22.043	10.401	.0961	197.43	18.981
49	6.833	.1463	151.67	22.195	10.921	.0916	208.35	19.077
50	7.107	.1407	158.77	22.341	11.467	.0872	219.82	19.169

COMPOUND INTEREST AND DISCOUNT TABLES

Years	Six per cent.				Years	Six per cent.			
	Am't of \$1 in <i>n</i> yrs.	Present val. of \$1 due in <i>n</i> yrs.	Am't of \$1 per annum in <i>n</i> yrs.	Present val. of \$1 annuity for <i>n</i> yrs.		Am't of \$1 in <i>n</i> yrs.	Present val. of \$1 due in <i>n</i> yrs.	Am't of \$1 per annum in <i>n</i> yrs.	Present val. of \$1 annuity for <i>n</i> yrs.
1	\$1.060	.9434	1 06	1.000	26	4.549	.2198	62.71	13.783
2	1.124	.8900	2 18	1.943	27	4.822	.2074	67.53	13.003
3	1.191	.8396	3 37	2.833	28	5.112	.1956	72.64	14.211
4	1.262	.7921	4.64	3.673	29	5.418	.1846	78.06	14.406
5	1.338	.7473	5.98	4.465	30	5.743	.1741	83.80	14.591
6	1.419	.7050	7.39	5.212	31	6.088	.1643	89.89	14.765
7	1.504	.6651	8.90	5.917	32	6.453	.1550	96.34	14.929
8	1.594	.6274	10.49	6.582	33	6.841	.1462	103.18	15.084
9	1.689	.5919	12.18	7.210	34	7.251	.1379	110.43	15.230
10	1.791	.5584	13.97	7.802	35	7.686	.1301	118.12	15.368
11	1.898	.5268	15.87	8.360	36	8.147	.1227	126.27	15.498
12	2.012	.4970	17.88	8.887	37	8.636	.1158	134.90	15.621
13	2.133	.4688	20.02	9.384	38	9.154	.1092	144.06	15.737
14	2.261	.4423	22.28	9.853	39	9.701	.1031	153.76	15.846
15	2.397	.4173	24.67	10.295	40	10.286	.0972	164.05	15.949
16	2.540	.3936	27.21	10.712	41	10.903	.0917	174.98	16.046
17	2.693	.3714	29.91	11.106	42	11.557	.0865	186.51	16.138
18	2.854	.3503	32.76	11.477	43	12.250	.0816	198.76	16.225
19	3.026	.3305	35.79	11.828	44	12.985	.0770	211.74	16.306
20	3.207	.3118	38.99	12.158	45	13.765	.0727	225.51	16.383
21	3.400	.2942	42.39	12.470	46	14.590	.0685	240.10	16.456
22	3.604	.2775	46.00	12.764	47	15.466	.0647	255.56	16.524
23	3.820	.2618	49.82	13.042	48	16.394	.0610	271.96	16.589
24	4.049	.2470	53.86	13.303	49	17.378	.0575	289.34	16.650
25	4.292	.2330	58.16	13.550	50	18.420	.0543	307.76	16.708

These tables are an abridgement of the seven-place tables in "Annuaire pour l'an 1913," published for the Bureau of Longitudes, by Gauthier-Villars, Quai des Grands-Augustins, 55; Paris, France.

**Bond Interest.**—The true return on a bond is not the interest rate divided by the purchase price, for if the bond be paid at par at maturity, the discount is earned if the bond was purchased below par, while if it was purchased above par, the premium must be amortized. If  $P$  is the price of a bond with  $n$  years to run;  $S$  the face of the bond,  $q$  the rate of interest current (expressed as a decimal);  $r$  the stipulated rate of the bond (as a decimal, .05, .06);  $x$  the interest on the investment,

$$\text{for annual payments } 1 + x = \left[ \frac{S[(q - r) + r(1 + q)^n]}{Pq} \right]^{1/n}$$

$$\text{for semiannual payments } 1 + x = \left[ \frac{S \left\{ (q - r)^2 + r \left( 1 + \frac{q}{2} \right)^{2n} \right\}}{Pq} \right]^{1/n}$$

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## ANNUAL INVESTMENT TABLE<sup>1</sup>

The sum of money which must be invested at the beginning of each year for a period of 1 to 50 years to amount to \$1000 at compound interest.

Years	2 Per cent.	3 Per cent.	3½ Per cent.	4 Per cent.	5 Per cent.	6 Per cent.	Years
1	\$980.39	970.87	966.18	961.55	952.38	943.39	1
2	485.43	478.24	474.83	471.25	464.47	457.88	2
3	320.31	314.07	311.04	307.98	302.11	296.30	3
4	237.87	232.07	229.20	226.45	220.95	215.66	4
5	188.40	182.88	180.18	177.53	172.35	167.36	5
6	155.42	150.08	147.51	144.97	140.02	135.24	6
7	131.87	126.71	124.19	121.74	116.97	112.39	7
8	114.22	109.18	106.74	104.35	99.73	95.32	8
9	100.50	95.57	93.19	90.86	86.37	82.10	9
10	89.53	84.69	82.36	80.09	75.72	71.57	10
11	80.57	75.80	73.52	71.30	67.04	63.01	11
12	73.10	68.41	66.17	63.99	59.83	55.92	12
13	66.78	62.17	59.96	57.83	53.77	49.96	13
14	61.38	56.82	54.66	52.57	48.59	44.89	14
15	56.69	52.20	50.07	48.02	44.14	40.53	15
16	52.60	48.16	46.07	44.06	40.26	36.75	16
17	48.99	44.61	42.55	40.58	36.86	33.44	17
18	45.79	41.46	39.44	37.49	33.85	30.53	18
19	42.92	38.65	36.66	34.75	31.19	27.94	19
20	40.35	36.13	34.17	32.29	28.80	25.65	20
21	38.02	33.86	31.92	30.08	26.66	23.59	21
22	35.91	31.79	29.89	28.08	24.73	21.74	22
23	33.99	29.92	28.04	26.26	22.90	20.07	23
24	32.23	28.20	26.35	24.60	21.40	18.57	24
25	30.61	26.63	24.81	23.09	19.95	17.20	25
26	29.12	25.18	23.39	21.70	18.63	15.95	26
27	27.74	23.85	22.08	20.42	17.42	14.81	27
28	26.46	22.61	20.87	19.24	16.31	13.77	28
29	25.27	21.47	19.75	18.15	15.28	12.81	29
30	24.17	20.41	18.72	17.14	14.33	11.93	30
31	23.13	19.42	17.75	16.21	13.46	11.12	31
32	22.17	18.49	16.85	15.34	12.65	10.38	32
33	21.26	17.63	16.01	14.52	11.90	9.69	33
34	20.41	16.82	15.23	13.76	11.20	9.06	34
35	19.61	16.06	14.49	13.06	10.54	8.47	35
36	18.86	15.34	13.80	12.39	9.94	7.92	36
37	18.14	14.67	13.15	11.77	9.37	7.41	37
38	17.47	14.04	12.54	11.18	8.84	6.94	38
39	16.83	13.44	11.97	10.64	8.35	6.50	39
40	16.23	12.88	11.43	10.12	7.88	6.10	40
41	15.66	12.34	10.92	9.63	7.45	5.72	41
42	15.11	11.84	10.43	9.17	7.04	5.36	42
43	14.60	11.36	9.98	8.74	6.66	5.03	43
44	14.11	10.90	9.54	8.33	6.30	4.72	44
45	13.64	10.47	9.13	7.94	5.97	4.43	45
46	13.20	10.06	8.74	7.57	5.64	4.16	46
47	12.78	9.66	8.37	7.23	5.34	3.91	47
48	12.37	9.29	8.02	6.90	5.06	3.67	48
49	11.97	8.94	7.69	6.59	4.79	3.45	49
50	11.60	8.61	7.37	6.29	4.55	3.25	50

<sup>1</sup> From "Lefax," Philadelphia, Penn.

# AMORTIZATION AND DEPRECIATION FORMULAS<sup>1</sup>

Amount of an annuity which at the end of  $n$  years will amortize a capital of \$1 (interest on annuity payments and on original capital figured at the same rate).

$$\text{Annuity} = \frac{r(1+r)^n}{(1+r)^n - 1} \cdot \$1$$

Present value of an annuity of \$1 per year, payable for  $n$  years, at the end of the year.

$$\text{Present value} = \frac{1}{r} \left[ 1 - \frac{1}{(1+r)^n} \right] \cdot \$1$$

The sum produced at the end of  $n$  years by placing annually \$1 at  $r$  interest, each dollar being deposited at the beginning of the year.

$$\text{Sum} = \frac{1+r}{r} [(1+r)^n - 1] \cdot \$1$$

Present worth of \$1 payable at the end of  $n$  years.

$$\text{Present worth} = \frac{\$1}{(1+r)^n}$$

Value at the end of  $n$  years of \$1 at compound interest.

$$\text{Value} = (1+r)^n \cdot \$1$$

## AREAS

Triangle = base  $\times \frac{1}{2}$  altitude

Triangle (let  $a$ ,  $b$ , and  $c$  be the sides and  $2s = a + b + c$ )

$$\text{Area} = \sqrt{s(s-a)(s-b)(s-c)}$$

Trapezoid =  $\frac{1}{2}$  sum of the bases  $\times$  the altitude

$$\text{Circle} = \pi r^2$$

$$\text{Sphere} = 4\pi r^2 = \pi d^2$$

$$\text{Cylinder (total surface)} = 2\pi r^2 + 2\pi rh \text{ (} h = \text{height or altitude)}$$

$$\text{Cylinder (cylindrical surface only)} = \pi db = 2\pi rh$$

$$\text{Cone} = \pi r^2 + 2\pi r \left( \frac{1}{2} \sqrt{r^2 + h^2} \right)$$

Regular polygons—where side =  $s$ , or  $r$  = apothem (radius of inscribed circle)

5 sides (pentagon)	$1.720477s^2 = 3.63271r^2$
6 sides (hexagon)	$2.598076s^2 = 3.46410r^2$
7 sides (heptagon)	$3.633912s^2 = 3.37101r^2$
8 sides (octagon)	$4.828427s^2 = 3.31371r^2$
9 sides (nonagon)	$6.181824s^2 = 3.27573r^2$
10 sides (decagon)	$7.694209s^2 = 3.24920r^2$
11 sides (undecagon)	$9.365640s^2 = 3.22903r^2$
12 sides (duodecagon)	$11.196152s^2 = 3.21539r^2$

$$\text{for } n \text{ sides, } A = \frac{n}{4} s^2 \cot \frac{180^\circ}{n} = nr^2 \tan \frac{180^\circ}{n}$$

<sup>1</sup> From "Annuaire pour 1915, Bureau des Longitudes." See p. 23 for bond interest formula.

**TABLE OF REGULAR POLYGONS**

No. of sides	Name of polygon	Area side = $S$ $A = cS^2$	Radius of circumscribed circle		Radius of inscribed circle, side = 1	Length of side, radius of circumscribed circle = 1	Angle at center	Angle between adjacent sides
			Perp. from center	Side = 1				
3	Triangle	0.4330127	2.000	0.5773	0.2887	1.7320	120°	60°
4	Square	1.0000000	1.414	0.7071	0.5000	1.4142	90°	90°
5	Pentagon	1.7204774	1.238	0.8506	0.6882	1.1756	72°	108°
6	Hexagon	2.5980762	1.115	1.0000	0.5660	1.0000	60°	120°
7	Heptagon	3.639124	1.110	1.1524	1.0383	0.8677	51°26'	128°34'
8	Octagon	4.8284271	1.083	1.3066	1.2071	0.7653	45°	135°
9	Nonagon	6.1818242	1.061	1.4619	1.3737	0.6840	40°	140°
10	Decagon	7.6942088	1.051	1.6180	1.5388	0.6180	26°	144°
11	Undecagon	9.3656399	1.042	1.7747	1.7028	0.5634	32°43'	147°16'21"
12	Duodecagon	11.1961524	1.037	1.9319	1.8660	0.5176	30°	150°

**TABLE OF THE REGULAR POLYHEDRONS WHOSE EDGE IS UNITY**

	No. of faces	Surface <sup>1</sup>	Volume <sup>2</sup>
Tetrahedron <sup>3</sup> . . . . .	4	1.7320508	0.1178513
Hexahedron (cube) <sup>3</sup> . . . . .	6	6.0000000	1.0000000
Octahedron <sup>3</sup> . . . . .	8	3.4641016	0.4717045
Dodecahedron <sup>3</sup> . . . . .	12	20.6457288	7.6631189
Icosahedron <sup>3</sup> . . . . .	20	8.6602540	2.1816950

<sup>1</sup>If the edge is not unity, multiply the constant in the table by the square of the side.

<sup>2</sup>If the edge is not unity, multiply the constant in the table by the cube of the side.

<sup>3</sup>The faces of the tetrahedron, octahedron and icosahedron (20 faces) are triangles; of the hexahedron, squares; and of the dodecahedron, pentagons.



**Circular Ring.**—Area =  $\pi (R^2 - r^2) = \pi(R - r)(R + r)$   
 $(R + r)$  = difference in areas between the inner and outer circles.



**Quadrant.**—Area =  $\frac{\pi r^2}{4} = 0.7854r^2 = 0.3927c^2$ .  
 $(c = \text{chord.})$



**Segment.**— $b$  = length of arc.  $\theta$  = angle in degrees.  $c$  = chord =  $\sqrt{4(2hr - h^2)}$   
 Area =  $\frac{1}{2}[br - c(r - h)]$   
 $= \pi r^2 \frac{\theta}{360} - \frac{c(r - h)}{2}$

When  $\theta$  is greater than 180°, then  $\frac{c}{2} \times \text{difference between } r \text{ and } h$  is added to the fraction  $\frac{\pi r^2 \theta}{360}$ .





**Sector.**—Area =  $\frac{1}{2}br = \pi r^2 \frac{\theta}{360^\circ}$

$\theta$  = angle in degrees  
 $b$  = length of arc



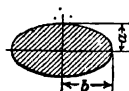
**Spandrel.**—Area =  $0.2146r^2 = 0.1073c^2$

**Parabola.**—Area =  $\frac{2}{3}sh$



$l$  = length of curved line = periphery —  $s = \frac{s^2}{8h}$

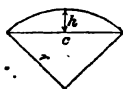
$\left\{ \sqrt{c(1+c)} + 2.0326 \times \log(\sqrt{c} + \sqrt{1+c}) \right\}$   
 where  $c = \left(\frac{4h}{s}\right)^2$



**Ellipse.**—Area =  $\pi ab$

**Circum.** =  $\pi(a+b) \frac{64 - 3\left(\frac{b-a}{b+a}\right)^4}{64 - 16\left(\frac{b-a}{b+a}\right)^2}$

[close approximation]



**Sector of Sphere.**—Total surface =  $\frac{\pi r}{2}(4h + c)$ ;

$c = 2\sqrt{(2hr - h^2)}$

Volume =  $\frac{2\pi r^2 h}{3} = \frac{2\pi r^2}{3} \left( r - \frac{\sqrt{4r^2 - c^2}}{2} \right)$

**Segment of Sphere.**—Spherical surface

=  $2\pi r h = \frac{\pi}{4}(c^2 + 4r^2)$

Total surface =  $2\pi r h + \frac{\pi}{4}c^2 = \frac{\pi}{2}(c^2 + 2h^2)$

Volume =  $\pi h^2 \left( r - \frac{h}{3} \right) = \pi h^2 \left( \frac{c^2 + 4h^2}{8h} - \frac{h}{3} \right)$

$c = 2\sqrt{2hr - h^2}$

**Frustum of Pyramid.**—(Area of top and bottom  $a$  and  $a'$  respectively).

Volume =  $\frac{h}{3}(a + a' + \sqrt{aa'})$

**Ellipsoid of Revolution.**—Volume =  $\frac{4\pi}{3}$  (product of the three radii).

**Paraboloid of Revolution.**—Volume =  $\frac{\pi r^2 h}{2}$

Curved surface =  $\frac{\pi}{6} \frac{r}{h^2} [(r^2 + 4h^2)^{3/2} - r^3]$



$$\cot \alpha = 1$$

$$\frac{1}{\tan \alpha} = \frac{\sqrt{1 - \sin^2 \alpha}}{\sin \alpha} = \frac{\cos \alpha}{\sqrt{1 - \cos^2 \alpha}} = \frac{1}{\sqrt{\sec^2 \alpha - 1}} = \sqrt{\operatorname{cosec}^2 \alpha - 1}$$

$$\sec \alpha =$$

$$\frac{1}{\cos \alpha} = \frac{1}{\sqrt{1 - \sin^2 \alpha}} = \sqrt{1 + \tan^2 \alpha} = \frac{\sqrt{1 + \cot^2 \alpha}}{\cot \alpha} = \frac{\operatorname{cosec} \alpha}{\sqrt{\operatorname{cosec}^2 \alpha - 1}}$$

$$\operatorname{cosec} \alpha =$$

$$\frac{1}{\sin \alpha} = \frac{1}{\sqrt{1 - \cos^2 \alpha}} = \frac{\sqrt{1 + \tan^2 \alpha}}{\tan \alpha} = \sqrt{1 + \cot^2 \alpha} = \frac{\sec \alpha}{\sqrt{\sec^2 \alpha - 1}}$$

$$\sin^2 \alpha + \cos^2 \alpha = 1, \tan \alpha = \frac{\sin \alpha}{\cos \alpha}; \cot \alpha = \frac{\cos \alpha}{\sin \alpha}$$

Rule for signs of trigonometric functions in various quadrants:

Quadrant	1	2	3	4
sin	+	+	-	-
cos	+	-	-	+
tan	+	-	+	-
cot	+	-	+	-
sec	+	-	-	+
cosec	+	+	-	-

Any function of  $0^\circ$  or an even multiple of  $90^\circ$ ,  $\left(\frac{\pi}{2}\right)$ , plus or minus  $A$ , is the same function of  $A$ , and any function of an odd multiple of  $90^\circ$  is the complementary function of  $A$ , the sign being determined for the appropriate quadrant by the above table.

$$\sin (x + y) = \sin x \cos y + \cos x \sin y, \sin 2x = 2 \sin x \cos x$$

$$\cos (x + y) = \cos x \cos y - \sin x \sin y, \cos 2x = \cos^2 x - \sin^2 x$$

$$\begin{aligned} \sin (x - y) &= \sin x \cos y - \cos x \sin y \\ \cos (x - y) &= \cos x \cos y + \sin x \sin y \end{aligned}$$

$$\tan (x + y) = \frac{\tan x + \tan y}{1 - \tan x \tan y}$$

$$\tan (x - y) = \frac{\tan x - \tan y}{1 + \tan x \tan y}$$

$$\cot (x + y) = \frac{\cot x \cot y - 1}{\cot y + \cot x}$$

$$\cot (x - y) = \frac{\cot x \cot y + 1}{\cot y - \cot x}$$

$$\frac{\sin (x + y)}{\sin (x - y)} = \frac{\tan x + \tan y}{\tan x - \tan y}$$

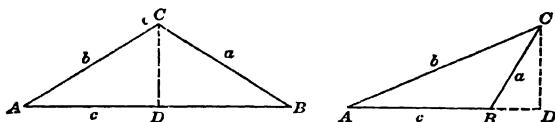
$$\frac{\cos (x + y)}{\cos (x - y)} = \frac{1 - \tan x \tan y}{1 + \tan x \tan y}$$

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$$\begin{aligned}
 \frac{\sin(x+y)}{\cos(x-y)} &= \frac{\tan x + \tan y}{1 + \tan x \tan y} \\
 \frac{\sin(x-y)}{\cos(x+y)} &= \frac{\tan x - \tan y}{1 - \tan x \tan y} \\
 \sin(x+y) \sin(x-y) &= \sin^2 x - \sin^2 y = \cos^2 y - \cos^2 x \\
 \cos(x+y) \cos(x-y) &= \cos^2 x - \sin^2 y = \cos^2 y - \sin^2 x \\
 \sin 2x &= 2 \sin x \cos x \\
 \cos 2x = \cos^2 x - \sin^2 x &= 2 \cos^2 x - 1 = 1 - 2 \sin^2 x \\
 \tan 2x &= \frac{2 \tan x}{1 - \tan^2 x} \\
 \cot 2x &= \frac{\cot^2 x - 1}{2 \cot x} \\
 \sin \frac{1}{2}x &= \sqrt{\frac{1 - \cos x}{2}} \\
 \cos \frac{1}{2}x &= \sqrt{\frac{1 + \cos x}{2}} \\
 \tan \frac{1}{2}x &= \frac{\sin x}{1 + \cos x} \\
 \cot \frac{1}{2}x &= \frac{\sin x}{1 - \cos x} \\
 \sin 3x &= 3 \sin x - 4 \sin^3 x \\
 \cos 3x &= 4 \cos^3 x - 3 \cos x \\
 \tan 3x &= \frac{3 \tan x - \tan^3 x}{1 - 3 \tan^2 x}
 \end{aligned}$$

#### Solution of Triangles

The solution of the right triangle is readily deduced from the functional equations applying to Fig. 1.



The solution of oblique triangles is given in the following formula:

$$\begin{aligned}
 a + b &= \frac{\sin A + \sin B}{\sin C} = \frac{\tan \frac{1}{2}(A+B)}{\tan \frac{1}{2}C} \\
 a - b &= \frac{\sin A - \sin B}{\sin C} = \frac{\tan \frac{1}{2}(A-B)}{\tan \frac{1}{2}C} \\
 a^2 &= b^2 + c^2 - 2bc \cos A \text{ or } c^2 = a^2 + b^2 - 2ac \cos C \\
 \cos A &= \frac{b^2 + c^2 - a^2}{2bc} \text{ or } \cos C = \frac{a^2 + b^2 - c^2}{2ab}
 \end{aligned}$$

$$\sin \frac{1}{2}A = \sqrt{\frac{(a+b-c)(a-b+c)}{4bc}} = \sqrt{\frac{(s-a)(s-b)}{bc}}$$

$$\cos \frac{1}{2}A = \sqrt{\frac{s(s-a)}{bc}}$$

$$\tan \frac{1}{2}A = \sqrt{\frac{(s-b)(s-c)}{bc}} \sqrt{\frac{bc}{s(s-a)}}$$

$$\sin A = 2 \sqrt{\frac{(s-b)(s-c)}{bc}} \sqrt{\frac{s(s-a)}{bc}}$$

$$\text{Area} = \frac{ab \sin C}{2} = \frac{bc \sin A}{2} = \frac{ac \sin B}{2} = \frac{b^2 \sin C \sin A}{2 \sin B} = \frac{\sqrt{s(s-a)(s-b)(s-c)}}{2}$$

$$\text{Radius of inscribed circle} = \frac{\text{area}}{\frac{1}{2} \text{perimeter}}$$

$$\text{Radius of circumscribed circle} = \frac{(\text{product of the sides})}{(\text{four times area})}$$

EXACT NUMERICAL VALUE OF THE FUNCTIONS OF SOME ANGLES

Angle	0°	30°	45°	60°	90°	120°	135°	150°	180°	270°	360°
Sine	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	-1	0
Cosine	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{1}{\sqrt{2}}$	$-\frac{\sqrt{3}}{2}$	-1	0	1
Tangent	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	$\infty$	$-\sqrt{3}$	-1	$-\frac{1}{\sqrt{3}}$	0	$\infty$	0
Cotangent	$\infty$	$\sqrt{3}$	1	$\frac{1}{\sqrt{3}}$	0	$-\frac{1}{\sqrt{3}}$	-1	$-\sqrt{3}$	$\infty$	0	$\infty$
Secant	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	$\infty$	-2	$-\sqrt{2}$	$-\frac{2}{\sqrt{3}}$	-1	$\infty$	1
Cosecant	$\infty$	2	$\sqrt{2}$	$\frac{2}{\sqrt{3}}$	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	$\infty$	-1	$\infty$
Versed sine	0	$\frac{2-\sqrt{3}}{2}$	$\frac{\sqrt{2}-1}{2}$	$\frac{1}{2}$	1	$\frac{3}{2}$	$\frac{1+\sqrt{2}}{\sqrt{2}}$	$\frac{2+\sqrt{3}}{2}$	2	1	0
Covers. sine	1	$\frac{1}{2}$	$\frac{\sqrt{2}-1}{\sqrt{2}}$	$\frac{2-\sqrt{3}}{2}$	0	$\frac{2-\sqrt{3}}{2}$	$\frac{\sqrt{2}-1}{\sqrt{2}}$	$\frac{1}{2}$	1	2	1

# 32. METALLURGISTS AND CHEMISTS' HANDBOOK

## SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
1	1	1	1.0000	1.0000	51	2601	132651	7.1414	3.7084
2	4	8	1.4142	1.2599	52	2704	140608	7.2111	3.7325
3	9	27	1.7321	1.4422	53	2809	148877	7.2801	3.7563
4	16	64	2.0000	1.5874	54	2916	157464	7.3485	3.7798
5	25	125	2.2361	1.7100	55	3025	166375	7.4162	3.8030
6	36	216	2.4495	1.8171	56	3136	175616	7.4833	3.8259
7	49	343	2.4495	1.9129	57	3249	185193	7.5498	3.8485
8	64	512	2.8284	2.0000	58	3364	195112	7.6158	3.8709
9	81	729	3.0000	2.0801	59	3481	205379	7.6811	3.8930
10	100	1000	3.1623	2.1544	60	3600	216000	7.7460	3.9149
11	121	1331	3.3166	2.2240	61	3721	226981	7.8102	3.9365
12	144	1728	3.6411	2.2894	62	3844	238328	7.8740	3.9579
13	169	2197	3.6056	2.3513	63	3969	250047	7.9373	3.9791
14	196	2744	3.7417	2.4101	64	4096	262144	8.0000	4.0000
15	225	3375	3.8730	2.4662	65	4225	274625	8.0623	4.0207
16	256	4096	4.0000	2.5108	66	4356	287496	8.1240	4.0412
17	289	4913	4.1231	2.5713	67	4489	300763	8.1854	4.0615
18	324	5832	4.2426	2.6207	68	4624	314432	8.2462	4.0817
19	361	6859	4.3589	2.6684	69	4761	328509	8.3066	4.1016
20	400	8000	4.4721	2.7144	70	4900	343000	8.3666	4.1213
21	441	9261	4.5826	2.7589	71	5041	357911	8.4261	4.1408
22	484	10648	4.6004	2.8020	72	5184	373248	8.4853	4.1602
23	529	12167	4.7058	2.8430	73	5329	389017	8.5440	4.1793
24	576	13824	4.8090	2.8845	74	5476	405224	8.6023	4.1983
25	625	15625	5.0000	2.9240	75	5625	421875	8.6603	4.2172
26	676	17576	5.0090	2.9625	76	5776	438976	8.7178	4.2358
27	729	19683	5.1962	3.0000	77	5929	456533	8.7750	4.2543
28	784	21052	5.2015	3.0366	78	6084	474552	8.8318	4.2727
29	841	24139	5.3852	3.0723	79	6241	493039	8.8882	4.2908
30	900	27000	5.4772	3.1072	80	6400	512000	8.9443	4.3089
31	961	29701	5.5678	3.1411	81	6561	531441	9.0000	4.3267
32	1024	32768	5.5660	3.1748	82	6724	551368	9.0554	4.3445
33	1089	35937	5.7446	3.2075	83	6889	571787	9.1104	4.3621
34	1156	39304	5.8110	3.2396	84	7056	592704	9.1652	4.3795
35	1225	42875	5.9161	3.2711	85	7225	614125	9.2195	4.3968
36	1296	46656	6.0000	3.3010	86	7396	636056	9.2736	4.4140
37	1369	50653	6.0828	3.3322	87	7569	658503	9.3276	4.4310
38	1444	54872	6.1644	3.3620	88	7744	681472	9.3808	4.4480
39	1521	59319	6.2450	3.3912	89	7921	704969	9.4340	4.4647
40	1600	64000	6.3246	3.4200	90	8100	729000	9.4868	4.4814
41	1681	68921	6.4031	3.4482	91	8281	753571	9.5394	4.4979
42	1764	74038	6.4807	3.4760	92	8464	778688	9.5917	4.5144
43	1849	79507	6.5574	3.5034	93	8649	804357	9.6437	4.5307
44	1936	85184	6.6332	3.5303	94	8836	830584	9.6954	4.5468
45	2025	91125	6.7082	3.5569	95	9025	857375	9.7468	4.5629
46	2116	97336	6.7823	3.5830	96	9216	884736	9.7980	4.5789
47	2209	103823	6.8557	3.6088	97	9409	912673	9.8489	4.5947
48	2304	110592	6.9282	3.6342	98	9604	941192	9.8995	4.6104
49	2401	117649	7.0000	3.6593	99	9801	970299	9.9499	4.6261
50	2500	125000	7.0711	3.6840	100	10000	1000000	10.0000	4.6416

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM  
1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
101	10201	1030301	10.0490	4.6570	151	22801	3442951	12.2882	5.3151
102	10404	1061208	10.0995	4.6723	152	23104	3511808	12.3288	5.3368
103	10609	1092727	10.1489	4.6875	153	23409	3581577	12.3693	5.3485
104	10816	1124864	10.1980	4.7027	154	23716	3652264	12.4097	5.3601
105	11025	1157625	10.2470	4.7177	155	24025	3723875	12.4499	5.3717
106	11236	1191016	10.2956	4.7326	156	24336	3796416	12.4900	5.3832
107	11449	1225043	10.3441	4.7475	157	24649	3866893	12.5300	5.3947
108	11664	1259712	10.3923	4.7622	158	24964	3944312	12.5698	5.4061
109	11881	1295029	10.4403	4.7769	159	25281	4019679	12.6095	5.4175
110	12100	1331000	10.4881	4.7914	160	25600	4096000	12.6491	5.4288
111	12321	1367631	10.5357	4.8059	161	25921	4173281	12.6886	5.4401
112	12544	1404928	10.5830	4.8203	162	26244	4251528	12.7279	5.4514
113	12769	1442897	10.6301	4.8346	163	26569	4330747	12.7671	5.4626
114	12996	1481544	10.6771	4.8488	164	26896	4410944	12.8062	5.4737
115	13225	1520875	10.7238	4.8629	165	27225	4492125	12.8452	5.4848
116	13456	1560896	10.7703	4.8770	166	27556	4574296	12.8841	5.4959
117	13689	1601613	10.8167	4.8910	167	27889	4657463	12.9228	5.5069
118	13924	1643032	10.8628	4.9049	168	28224	4741632	12.9615	5.5178
119	14161	1685150	10.9087	4.9187	169	28561	4826809	13.0000	5.5288
120	14400	1728000	10.9545	4.9324	170	28900	4913000	13.0384	5.5397
121	14641	1771561	11.0000	4.9461	171	29241	5000211	13.0767	5.5505
122	14884	1815848	11.0454	4.9597	172	29584	5088448	13.1149	5.5613
123	15129	1860867	11.0905	4.9732	173	29929	5177717	13.1530	5.5721
124	15376	1906624	11.1355	4.9866	174	30276	5268024	13.1909	5.5828
125	15625	1953125	11.1803	5.0000	175	30625	5359375	13.2288	5.5934
126	15876	2000376	11.2250	5.0133	176	30976	5451776	13.2665	5.6041
127	16129	2048383	11.2694	5.0265	177	31329	5545233	13.3041	5.6147
128	16384	2097152	11.3137	5.0397	178	31684	5639752	13.3417	5.6252
129	16641	2146689	11.3578	5.0528	179	32041	5735339	13.3791	5.6357
130	16900	2197000	11.4018	5.0658	180	32400	5832000	13.4164	5.6462
131	17161	2248091	11.4455	5.0788	181	32761	5929741	13.4536	5.6567
132	17424	2299968	11.4891	5.0916	182	33124	6028568	13.4907	5.6671
133	17689	2352637	11.5326	5.1045	183	33489	6128487	13.5277	5.6774
134	17956	2406104	11.5758	5.1172	184	33856	6229504	13.5647	5.6877
135	18225	2460375	11.6190	5.1299	185	34225	6331625	13.6015	5.6980
136	18496	2515456	11.6619	5.1426	186	34596	6434856	13.6382	5.7083
137	18769	2571353	11.7047	5.1551	187	34969	6539203	13.6748	5.7185
138	19044	2628072	11.7473	5.1676	188	35344	6644672	13.7113	5.7287
139	19321	2685619	11.7898	5.1801	189	35721	6751269	13.7477	5.7388
140	19600	2744000	11.8322	5.1925	190	36100	6859000	13.7840	5.7489
141	19881	2803221	11.8743	5.2048	191	36481	6967871	13.8203	5.7590
142	20164	2863288	11.9164	5.2171	192	36864	7077888	13.8564	5.7690
143	20449	2924207	11.9583	5.2293	193	37249	7189057	13.8924	5.7790
144	20736	2985984	12.0000	5.2415	194	37636	7301384	13.9284	5.7890
145	21025	3048625	12.0416	5.2536	195	38025	7414875	13.9642	5.7989
146	21316	3112136	12.0830	5.2656	196	38416	7529536	14.0000	5.8088
147	21609	3176523	12.1244	5.2776	197	38809	7645373	14.0357	5.8186
148	21904	3241792	12.1655	5.2896	198	39204	7762302	14.0712	5.8285
149	22201	3307949	12.2066	5.3015	199	39601	7880509	14.1067	5.8383
150	22500	3375000	12.2474	5.3133	200	40000	8000000	14.1421	5.8480

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SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM  
1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
201	40401	8120601	14.1774	5.8578	251	63001	15813251	15.8430	6.3080
202	40804	8242408	14.2127	5.8675	252	63504	16003008	15.8745	6.3164
203	41209	8365427	14.2478	5.8771	253	64009	16194277	15.9060	6.3247
204	41616	8489664	14.2829	5.8868	254	64516	16387064	15.9374	6.3330
205	42025	8615125	14.3178	5.8964	255	65025	16581375	15.9687	6.3413
206	42436	8741816	14.3527	5.9059	256	65536	16777216	16.0000	6.3496
207	42849	8869743	14.3875	5.9155	257	66049	16974593	16.0312	6.3579
208	43264	8998912	14.4222	5.9250	258	66564	17173512	16.0624	6.3661
209	43681	9129329	14.4568	5.9345	259	67081	17373979	16.0935	6.3743
210	44100	9261000	14.4914	5.9439	260	67600	17576000	16.1245	6.3825
211	44521	9393931	14.5258	5.9533	261	68121	17779581	16.1555	6.3907
212	44944	9528128	14.5602	5.9627	262	68644	17984728	16.1864	6.3988
213	45369	9663597	14.5945	5.9721	263	69169	18191447	16.2173	6.4070
214	45796	9800344	14.6287	5.9814	264	69696	18399744	16.2481	6.4151
215	46225	9938375	14.6629	5.9907	265	70225	18609625	16.2788	6.4232
216	46656	10077696	14.6969	6.0000	266	70756	18821096	16.3095	6.4312
217	47089	10218313	14.7307	6.0092	267	71289	19034163	16.3401	6.4393
218	47524	10360232	14.7648	6.0185	268	71824	19248832	16.3707	6.4473
219	47961	10503459	14.7986	6.0277	269	72361	19465109	16.4012	6.4553
220	48400	10648000	14.8324	6.0368	270	72900	19683000	16.4317	6.4633
221	48841	10793861	14.8661	6.0459	271	73441	19902511	16.4621	6.4713
222	49284	10941048	14.9007	6.0550	272	73984	20123648	16.4924	6.4792
223	49729	11089567	14.9352	6.0641	273	74529	20346417	16.5227	6.4872
224	50176	11239424	14.9696	6.0732	274	75076	20570824	16.5529	6.4951
225	50625	11390625	15.0000	6.0822	275	75625	20796875	16.5831	6.5030
226	51076	11543176	15.0333	6.0912	276	76176	21024576	16.6132	6.5108
227	51529	11697083	15.0665	6.1002	277	76729	21253933	16.6433	6.5187
228	51984	11852352	15.0997	6.1091	278	77284	21484952	16.6733	6.5265
229	52441	12008989	15.1327	6.1180	279	77841	21717639	16.7033	6.5343
230	52900	12167000	15.1656	6.1269	280	78400	21952000	16.7332	6.5421
231	53361	12326391	15.1987	6.1358	281	78961	22188041	16.7631	6.5499
232	53824	12487168	15.2315	6.1446	282	79524	22425768	16.7929	6.5577
233	54289	12649337	15.2643	6.1534	283	80089	22665187	16.8226	6.5654
234	54756	12812904	15.2971	6.1622	284	80656	22906304	16.8523	6.5731
235	55225	12977875	15.3297	6.1710	285	81225	23149125	16.8819	6.5808
236	55696	13144256	15.3623	6.1797	286	81796	23393656	16.9115	6.5885
237	56169	13312053	15.3948	6.1884	287	82369	23639903	16.9411	6.5962
238	56644	13481272	15.4272	6.1972	288	82944	23887872	16.9706	6.6039
239	57121	13651919	15.4596	6.2058	289	83521	24137569	17.0000	6.6115
240	57600	13824000	15.4919	6.2145	290	84100	24389000	17.0294	6.6191
241	58081	13997581	15.5242	6.2231	291	84681	24642171	17.0587	6.6267
242	58564	14172488	15.5563	6.2317	292	85264	24897088	17.0880	6.6343
243	59049	14349007	15.5885	6.2403	293	85849	25153757	17.1172	6.6419
244	59536	14526784	15.6205	6.2488	294	86436	25412184	17.1464	6.6494
245	60025	14706125	15.6525	6.2573	295	87025	25672375	17.1756	6.6569
246	60516	14886936	15.6844	6.2658	296	87616	25934336	17.2047	6.6644
247	61009	15069229	15.7162	6.2743	297	88209	26198073	17.2337	6.6719
248	61504	15252992	15.7480	6.2828	298	88804	26463592	17.2627	6.6794
249	62001	15438249	15.7797	6.2912	299	89401	26730899	17.2916	6.6869
250	62500	15625000	15.8114	6.2996	300	90000	27000000	17.3205	6.6943



SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1, TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
301	90601	27270901	17.3494	6.7018	351	123201	43243551	18.7350	7.0540
302	91204	27543608	17.3781	6.7092	352	123904	43614208	18.7617	7.0607
303	91809	27818127	17.4069	6.7166	353	124609	43986977	18.7883	7.0674
304	92416	28094464	17.4356	6.7240	354	125316	44361864	18.8149	7.0740
305	93025	28372625	17.4642	6.7313	355	126025	44738875	18.8414	7.0807
306	93636	28652616	17.4929	6.7387	356	126736	45118093	18.8680	7.0873
307	94249	28934443	17.5214	6.7460	357	127449	45499293	18.8944	7.0940
308	94864	29218112	17.5499	6.7533	358	128164	45882712	18.9209	7.1006
309	95481	29503620	17.5784	6.7606	359	128881	46268279	18.9473	7.1072
310	96100	29791000	17.6068	6.7679	360	129600	46656000	18.9737	7.1138
311	96721	30080231	17.6352	6.7752	361	130321	47045881	19.0000	7.1204
312	97344	30371328	17.6635	6.7824	362	131044	47437928	19.0263	7.1269
313	97969	30664297	17.6918	6.7897	363	131769	47832147	19.0526	7.1335
314	98596	30959144	17.7200	6.7969	364	132496	48228544	19.0788	7.1400
315	99225	31255875	17.7482	6.8041	365	133225	48627125	19.1050	7.1466
316	99856	31554496	17.7764	6.8113	366	133956	49027896	19.1311	7.1531
317	100489	31855013	17.8045	6.8185	367	134689	49430863	19.1572	7.1596
318	101124	32157432	17.8326	6.8256	368	135424	49836032	19.1833	7.1661
319	101761	32461759	17.8606	6.8328	369	136161	50243409	19.2094	7.1726
320	102400	32768000	17.8885	6.8399	370	136900	50653000	19.2354	7.1791
321	103041	33076161	17.9165	6.8470	371	137641	51064811	19.2614	7.1855
322	103684	33386248	17.9444	6.8541	372	138384	51478848	19.2873	7.1920
323	104329	33698267	17.9722	6.8612	373	139129	51895117	19.3132	7.1984
324	104976	34012224	18.0000	6.8683	374	139876	52313624	19.3391	7.2048
325	105625	34328125	18.0278	6.8753	375	140625	52734375	19.3649	7.2112
326	106276	34645076	18.0555	6.8824	376	141376	53157376	19.3907	7.2177
327	106929	34965783	18.0831	6.8894	377	142129	53582633	19.4165	7.2240
328	107584	35287552	18.1108	6.8964	378	142884	54010152	19.4422	7.2304
329	108241	35611289	18.1384	6.9034	379	143641	54439939	19.4679	7.2368
330	108900	35937000	18.1659	6.9104	380	144400	54872000	19.4936	7.2432
331	109561	36264691	18.1934	6.9174	381	145161	55306341	19.5192	7.2495
332	110224	36594368	18.2209	6.9244	382	145924	55742968	19.5448	7.2558
333	110889	36926037	18.2483	6.9313	383	146689	56181887	19.5704	7.2622
334	111556	37259704	18.2757	6.9382	384	147456	56623104	19.5959	7.2685
335	112225	37595375	18.3030	6.9451	385	148225	57066625	19.6214	7.2748
336	112896	37933056	18.3303	6.9521	386	148996	57512456	19.6469	7.2811
337	113569	38272753	18.3576	6.9589	387	149769	57960603	19.6723	7.2874
338	114244	38614472	18.3848	6.9658	388	150544	58411072	19.6977	7.2936
339	114921	38958219	18.4120	6.9727	389	151321	58863869	19.7231	7.2999
340	115600	39304000	18.4391	6.9795	390	152100	59319000	19.7484	7.3061
341	116281	39651821	18.4662	6.9864	391	152881	59776471	19.7737	7.3124
342	116964	40001688	18.4932	6.9932	392	153664	60236288	19.7990	7.3186
343	117649	40353607	18.5203	7.0000	393	154449	60698457	19.8242	7.3248
344	118336	40707584	18.5472	7.0068	394	155236	61162984	19.8494	7.3310
345	119025	41063625	18.5742	7.0136	395	156025	61629875	19.8746	7.3372
346	119716	41421736	18.6011	7.0203	396	156816	62099136	19.8997	7.3434
347	120409	41781923	18.6279	7.0271	397	157609	62570773	19.9249	7.3496
348	121104	42144192	18.6548	7.0338	398	158404	63044792	19.9500	7.3558
349	121801	42508549	18.6815	7.0406	399	159201	63521199	19.9750	7.3619
350	122500	42875000	18.7083	7.0473	400	160000	64000000	20.0000	7.3681

# 36. METALLURGISTS AND CHEMISTS' HANDBOOK

## SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
401	160801	64481201	20.0250	7.3742	451	203401	91733851	21.2368	7.6688
402	161604	64964808	20.0499	7.3803	452	204304	92345408	21.2603	7.6744
403	162409	65450827	20.0749	7.3864	453	205209	92959677	21.2838	7.6800
404	163216	65939204	20.0998	7.3925	454	206116	93576604	21.3073	7.6857
405	164025	66430125	20.1246	7.3986	455	207025	94196375	21.3307	7.6914
406	164836	66923416	20.1494	7.4047	456	207936	94818816	21.3542	7.6970
407	165649	67419143	20.1742	7.4108	457	208849	95443393	21.3776	7.7026
408	166464	67917312	20.1990	7.4169	458	209764	96071912	21.4009	7.7082
409	167281	68417929	20.2237	7.4229	459	210681	96702579	21.4243	7.7138
410	168100	68921000	20.2485	7.4290	460	211600	97336000	21.4476	7.7194
411	168921	69426531	20.2731	7.4350	461	212521	97972181	21.4709	7.7250
412	169744	69934528	20.2978	7.4410	462	213444	98611128	21.4942	7.7306
413	170569	70444997	20.3224	7.4470	463	214369	99252847	21.5174	7.7362
414	171396	70957944	20.3470	7.4530	464	215296	99897344	21.5407	7.7418
415	172225	71473375	20.3715	7.4590	465	216225	100544625	21.5639	7.7473
416	173056	71991296	20.3961	7.4650	466	217156	101194966	21.5870	7.7529
417	173889	72511713	20.4206	7.4710	467	218089	101847563	21.6102	7.7584
418	174724	73034632	20.4450	7.4770	468	219024	102501232	21.6333	7.7639
419	175561	73560059	20.4695	7.4829	469	219961	103161709	21.6564	7.7695
420	176400	74088000	20.4939	7.4889	470	220900	103823300	21.6795	7.7750
421	177241	74618461	20.5183	7.4948	471	221841	104487111	21.7025	7.7805
422	178084	75151448	20.5426	7.5007	472	222784	105154048	21.7255	7.7860
423	178929	75686967	20.5670	7.5067	473	223729	105823817	21.7486	7.7915
424	179776	76225024	20.5913	7.5126	474	224676	106496124	21.7715	7.7970
425	180625	76765625	20.6155	7.5185	475	225625	107171875	21.7945	7.8025
426	181476	77308776	20.6398	7.5244	476	226576	107850176	21.8174	7.8079
427	182329	77854423	20.6640	7.5302	477	227529	108531333	21.8403	7.8134
428	183184	78402752	20.6882	7.5361	478	228484	109215352	21.8632	7.8188
429	184041	78953589	20.7124	7.5420	479	229441	109902230	21.8861	7.8243
430	184900	79507000	20.7364	7.5478	480	230400	110592000	21.9089	7.8297
431	185761	80062997	20.7605	7.5537	481	231361	111284641	21.9317	7.8352
432	186624	80621568	20.7846	7.5595	482	232324	111980168	21.9545	7.8406
433	187489	81182737	20.8087	7.5654	483	233289	112678587	21.9773	7.8460
434	188356	81746504	20.8327	7.5712	484	234256	113379904	22.0000	7.8514
435	189225	82312875	20.8567	7.5770	485	235225	114084125	22.0227	7.8568
436	190096	82881856	20.8806	7.5828	486	236196	114791256	22.0454	7.8622
437	190969	83453453	20.9045	7.5886	487	237169	115501303	22.0681	7.8676
438	191844	84027672	20.9284	7.5944	488	238144	116214272	22.0907	7.8730
439	192721	84604519	20.9523	7.6001	489	239121	116930169	22.1133	7.8784
440	193600	85184000	20.9762	7.6059	490	240100	117649000	22.1359	7.8837
441	194481	85766121	21.0000	7.6117	491	241081	118370771	22.1585	7.8891
442	195364	86350888	21.0238	7.6174	492	242064	119095488	22.1811	7.8944
443	196249	86938307	21.0476	7.6232	493	243049	119823157	22.2036	7.8998
444	197136	87528384	21.0713	7.6289	494	244036	120553784	22.2261	7.9051
445	198025	88121125	21.0950	7.6346	495	245025	121287375	22.2486	7.9105
446	198916	88716536	21.1187	7.6403	496	246016	122023936	22.2711	7.9158
447	199809	89314623	21.1424	7.6460	497	247009	122763473	22.2935	7.9211
448	200704	89915302	21.1660	7.6517	498	248004	123505992	22.3159	7.9264
449	201601	90518849	21.1896	7.6574	499	249001	124251499	22.3383	7.9317
450	202500	91125000	21.2132	7.6631	500	250000	125000000	22.3607	7.9370

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM  
1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
501	251001	125751501	22.3830	7.9423	551	303601	167284151	23.4734	8.1982
502	252004	126506008	22.4054	7.9476	552	304704	168190608	23.4947	8.2031
503	253009	127263527	22.4277	7.9528	553	305809	169112377	23.5160	8.2081
504	254016	128024064	22.4499	7.9581	554	306916	170031464	23.5372	8.2130
505	255025	128787625	22.4722	7.9634	555	308025	170953875	23.5584	8.2180
506	256036	129554216	22.4944	7.9686	556	309136	171879616	23.5797	8.2229
507	257049	130323843	22.5167	7.9739	557	310249	172808993	23.6008	8.2278
508	258064	131096512	22.5389	7.9791	558	311364	173741112	23.6220	8.2327
509	259081	131872220	22.5610	7.9843	559	312481	174676879	23.6432	8.2377
510	260100	132651000	22.5832	7.9896	560	313600	175616000	23.6643	8.2426
511	261121	133432831	22.6053	7.9948	561	314721	176558481	23.6854	8.2475
512	262144	134217728	22.6274	8.0000	562	315844	177504328	23.7065	8.2524
513	263169	135005697	22.6495	8.0052	563	316969	178453547	23.7276	8.2573
514	264196	135796744	22.6716	8.0104	564	318096	179406144	23.7487	8.2621
515	265225	136590875	22.6936	8.0156	565	319225	180362125	23.7697	8.2670
516	266256	137388096	22.7156	8.0208	566	320356	181321406	23.7908	8.2719
517	267289	138188413	22.7376	8.0260	567	321489	182284263	23.8118	8.2768
518	268324	138991832	22.7596	8.0311	568	322624	183250432	23.8328	8.2816
519	269361	139798359	22.7816	8.0363	569	323761	184220009	23.8537	8.2865
520	270400	140608000	22.8035	8.0415	570	324900	185193000	23.8747	8.2913
521	271441	141420761	22.8254	8.0466	571	326041	186169411	23.8956	8.2962
522	272484	142236648	22.8473	8.0517	572	327184	187149248	23.9165	8.3010
523	273529	143055607	22.8692	8.0569	573	328329	188132517	23.9374	8.3059
524	274576	143877824	22.8910	8.0620	574	329476	189119224	23.9583	8.3107
525	275625	144703125	22.9129	8.0671	575	330625	190109375	23.9792	8.3155
526	276676	145531576	22.9347	8.0723	576	331776	191102976	24.0000	8.3203
527	277729	146363183	22.9565	8.0774	577	332929	192100033	24.0208	8.3251
528	278784	147197952	22.9783	8.0825	578	334084	193100552	24.0416	8.3300
529	279841	148035889	23.0000	8.0876	579	335241	194104539	24.0624	8.3348
530	280900	148877000	23.0217	8.0927	580	336400	195112000	24.0832	8.3396
531	281961	149721291	23.0434	8.0978	581	337561	196122941	24.1039	8.3443
532	283024	150568768	23.0651	8.1028	582	338724	197137368	24.1247	8.3491
533	284089	151419437	23.0868	8.1079	583	339889	198155287	24.1454	8.3539
534	285156	152273304	23.1084	8.1130	584	341056	199176704	24.1661	8.3587
535	286225	153130375	23.1301	8.1180	585	342225	200201625	24.1868	8.3634
536	287296	153990656	23.1517	8.1231	586	343396	201230056	24.2074	8.3682
537	288369	154854153	23.1733	8.1281	587	344569	202262003	24.2281	8.3730
538	289444	155720872	23.1948	8.1332	588	345744	203297472	24.2487	8.3777
539	290521	156590819	23.2164	8.1382	589	346921	204336469	24.2693	8.3825
540	291600	157464000	23.2379	8.1433	590	348100	205379000	24.2899	8.3872
541	292681	158340421	23.2594	8.1483	591	349281	206425071	24.3105	8.3919
542	293764	159220088	23.2809	8.1533	592	350464	207474688	24.3311	8.3967
543	294849	160103007	23.3024	8.1583	593	351649	208527857	24.3516	8.4014
544	295936	160989184	23.3238	8.1633	594	352836	209584584	24.3721	8.4061
545	297025	161878625	23.3452	8.1683	595	354025	210644875	24.3926	8.4108
546	298116	162771336	23.3666	8.1733	596	355216	211708736	24.4131	8.4155
547	299209	163667323	23.3880	8.1783	597	356409	212776173	24.4336	8.4202
548	300304	164566592	23.4094	8.1833	598	357604	213847192	24.4540	8.4249
549	301401	165469149	23.4307	8.1882	599	358801	214921799	24.4745	8.4296
550	302500	166375000	23.4521	8.1932	600	360000	216000000	24.4949	8.4343

# 38 METALLURGISTS AND CHEMISTS' HANDBOOK

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM  
1 TO 1000. *Continued*

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
601	361201	217081801	24.5153	8.4390	651	423801	275894451	25.5147	8.6668
602	362404	218167208	24.5357	8.4437	652	425104	277167808	25.5343	8.6713
603	363609	219256227	24.5561	8.4484	653	426409	278445077	25.5539	8.6757
604	364816	220348864	24.5764	8.4530	654	427716	279726264	25.5734	8.6801
605	366025	221445125	24.5967	8.4577	655	429025	281011375	25.5930	8.6845
606	367236	222545016	24.6171	8.4623	656	430336	282300416	25.6125	8.6890
607	368449	223648543	24.6374	8.4670	657	431649	283593393	25.6320	8.6934
608	369664	224755712	24.6577	8.4716	658	432964	284890312	25.6515	8.6978
609	370881	225866529	24.6779	8.4763	659	434281	286191179	25.6710	8.7022
610	372100	226981000	24.6982	8.4809	660	435600	287496000	25.6905	8.7066
611	373321	228099131	24.7184	8.4856	661	436921	288804781	25.7099	8.7110
612	374544	229220928	24.7386	8.4902	662	438244	290117528	25.7294	8.7154
613	375769	230346397	24.7588	8.4948	663	439569	291434247	25.7488	8.7198
614	376996	231475544	24.7790	8.4994	664	440896	292754944	25.7682	8.7241
615	378225	232608375	24.7992	8.5040	665	442225	294079625	25.7876	8.7285
616	379456	233744896	24.8193	8.5086	666	443556	295408296	25.8070	8.7329
617	380689	234885113	24.8395	8.5132	667	444889	296740963	25.8263	8.7373
618	381924	236029032	24.8597	8.5178	668	446224	298077632	25.8457	8.7416
619	383161	237176659	24.8797	8.5224	669	447561	299419139	25.8650	8.7460
620	384400	238328000	24.8998	8.5270	670	448900	300763000	25.8844	8.7503
621	385641	239483061	24.9199	8.5316	671	450241	302111711	25.9037	8.7547
622	386884	240641848	24.9399	8.5362	672	451584	303464448	25.9230	8.7590
623	388129	241804367	24.9600	8.5408	673	452929	304821217	25.9422	8.7634
624	389376	242970624	24.9800	8.5453	674	454276	306182024	25.9615	8.7677
625	390625	244140625	25.0000	8.5499	675	455625	307546875	25.9808	8.7721
626	391876	245314376	25.0200	8.5544	676	456976	308915776	26.0000	8.7764
627	393129	246491883	25.0400	8.5590	677	458329	310288733	26.0192	8.7807
628	394384	247673152	25.0599	8.5635	678	459684	311665752	26.0384	8.7850
629	395641	248858189	25.0799	8.5681	679	461041	313046839	26.0576	8.7893
630	396900	250047000	25.0999	8.5726	680	462400	314432000	26.0768	8.7937
631	398161	251240591	25.1197	8.5772	681	463761	315821241	26.0960	8.7980
632	399424	252439968	25.1396	8.5817	682	465124	317214568	26.1151	8.8023
633	400689	253646137	25.1595	8.5862	683	466489	318611987	26.1343	8.8066
634	401956	254860104	25.1794	8.5907	684	467856	320013504	26.1534	8.8109
635	403225	256081875	25.1992	8.5952	685	469225	321419125	26.1725	8.8152
636	404496	257309456	25.2190	8.5997	686	470596	322828856	26.1916	8.8194
637	405769	258547483	25.2389	8.6043	687	471969	324242703	26.2107	8.8237
638	407044	259796072	25.2587	8.6088	688	473344	325660672	26.2298	8.8280
639	408321	260991719	25.2784	8.6132	689	474721	327082769	26.2488	8.8323
640	409600	262144000	25.2982	8.6177	690	476100	328509000	26.2679	8.8366
641	410881	263374721	25.3180	8.6222	691	477481	329939371	26.2869	8.8408
642	412164	264609288	25.3377	8.6267	692	478864	331373888	26.3059	8.8451
643	413449	265847707	25.3574	8.6312	693	480249	332812557	26.3249	8.8493
644	414736	267089084	25.3772	8.6357	694	481636	334255384	26.3439	8.8536
645	416025	268336125	25.3969	8.6401	695	483025	335702375	26.3629	8.8578
646	417316	269586136	25.4165	8.6446	696	484416	337153536	26.3818	8.8621
647	418609	270840003	25.4362	8.6490	697	485809	338608873	26.4008	8.8663
648	419904	272097791	25.4558	8.6535	698	487204	340068392	26.4197	8.8706
649	421201	273359449	25.4755	8.6579	699	488601	341532099	26.4386	8.8748
650	422500	274625000	25.4951	8.6624	700	490000	343000000	26.4575	8.8790

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM  
1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
701	491401	344472101	26.4764	8.8833	751	564001	423564751	27.4044	9.0806
702	492804	345948408	26.4953	8.8875	752	565504	425259008	27.4226	9.0937
703	494209	347428927	26.5141	8.8917	753	567009	426953777	27.4408	9.0977
704	495616	348913664	26.5330	8.8959	754	568516	428661064	27.4591	9.1017
705	497025	350402625	26.5518	8.9001	755	570025	430368875	27.4773	9.1057
706	498436	351895816	26.5707	8.9043	756	571536	432081216	27.4955	9.1098
707	499849	353393243	26.5895	8.9085	757	573049	433798093	27.5136	9.1138
708	501264	354894912	26.6083	8.9127	758	574564	435519512	27.5318	9.1178
709	502681	356400820	26.6271	8.9169	759	576081	437245479	27.5500	9.1218
710	504100	357911000	26.6458	8.9211	760	577600	438976000	27.5681	9.1258
711	505521	359425431	26.6646	8.9253	761	579121	440711081	27.5862	9.1298
712	506944	360944128	26.6833	8.9295	762	580644	442450728	27.6043	9.1338
713	508369	362467097	26.7021	8.9337	763	582169	444194947	27.6225	9.1378
714	509796	363994344	26.7208	8.9378	764	583696	445943744	27.6405	9.1418
715	511225	365525875	26.7395	8.9420	765	585225	447697125	27.6586	9.1458
716	512656	367061606	26.7582	8.9462	766	586756	449455096	27.6767	9.1498
717	514089	368601813	26.7769	8.9503	767	588289	451217663	27.6948	9.1537
718	515524	370146332	26.7955	8.9545	768	589824	452984832	27.7128	9.1577
719	516961	371694950	26.8142	8.9587	769	591361	454756609	27.7308	9.1617
720	518400	373248000	26.8328	8.9628	770	592900	456533000	27.7489	9.1657
721	519841	374805361	26.8514	8.9670	771	594441	458314011	27.7669	9.1696
722	521284	376367048	26.8701	8.9711	772	595984	460099048	27.7849	9.1736
723	522729	377933007	26.8887	8.9752	773	597529	461889917	27.8029	9.1775
724	524176	379503424	26.9072	8.9794	774	599076	463684824	27.8209	9.1815
725	525625	381078125	26.9258	8.9835	775	600625	465484375	27.8388	9.1855
726	527076	382657176	26.9444	8.9876	776	602176	467288576	27.8568	9.1894
727	528529	384240583	26.9629	8.9918	777	603729	469097433	27.8747	9.1933
728	529984	385828352	26.9815	8.9959	778	605284	470910952	27.8927	9.1973
729	531441	387420489	27.0000	9.0000	779	606841	472729139	27.9106	9.2012
730	532900	389017000	27.0185	9.0041	780	608400	474552000	27.9285	9.2052
731	534361	390617891	27.0370	9.0082	781	609961	476379541	27.9464	9.2091
732	535824	392223168	27.0555	9.0123	782	611524	478211768	27.9643	9.2130
733	537289	393832837	27.0740	9.0164	783	613089	480048687	27.9821	9.2170
734	538756	395446904	27.0924	9.0205	784	614656	481890304	28.0000	9.2209
735	540225	397065375	27.1109	9.0246	785	616225	483736625	28.0179	9.2248
736	541696	398688256	27.1293	9.0287	786	617796	485587656	28.0357	9.2287
737	543169	400315553	27.1477	9.0328	787	619369	487443403	28.0535	9.2326
738	544644	401947272	27.1662	9.0369	788	620944	489303872	28.0713	9.2365
739	546121	403583419	27.1846	9.0410	789	622521	491169009	28.0891	9.2404
740	547600	405224000	27.2029	9.0450	790	624100	493039000	28.1069	9.2443
741	549081	406869021	27.2213	9.0491	791	625681	494913671	28.1247	9.2482
742	550564	408518488	27.2397	9.0532	792	627264	496793088	28.1425	9.2521
743	552049	410172407	27.2580	9.0572	793	628849	498677257	28.1603	9.2560
744	553536	411830784	27.2764	9.0613	794	630436	500566184	28.1780	9.2599
745	555025	413493625	27.2947	9.0654	795	632025	502459875	28.1957	9.2638
746	556516	415160936	27.3130	9.0694	796	633616	504358336	28.2135	9.2677
747	558009	416832723	27.3313	9.0735	797	635209	506261573	28.2312	9.2716
748	559504	418508992	27.3496	9.0775	798	636804	508169592	28.2489	9.2754
749	561001	420189740	27.3679	9.0816	799	638401	510082399	28.2666	9.2793
750	562500	421875000	27.3861	9.0856	800	640000	512000000	28.2843	9.2832

# 40. METALLURGISTS AND CHEMISTS' HANDBOOK

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM  
1 TO 1000. *Continued*

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
801	641601	513922401	28.3019	9.2870	851	724201	616295051	29.1719	9.4764
802	643204	515849608	28.3196	9.2909	852	725904	618470208	29.1890	9.4801
803	644809	517781627	28.3373	9.2948	853	727609	620650477	29.2062	9.4838
804	646416	519718404	28.3549	9.2986	854	729316	622835864	29.2233	9.4875
805	648025	521660125	28.3725	9.3025	855	731025	625026375	29.2404	9.4912
806	649636	523606616	28.3901	9.3063	856	732736	627222016	29.2575	9.4949
807	651249	525557943	28.4077	9.3102	857	734449	629422793	29.2746	9.4986
808	652864	527514112	28.4253	9.3140	858	736164	631628712	29.2916	9.5023
809	654481	529475129	28.4429	9.3179	859	737881	633839779	29.3087	9.5060
810	656100	531441000	28.4605	9.3217	860	739600	636056000	29.3258	9.5097
811	657721	533411731	28.4781	9.3255	861	741321	638277381	29.3428	9.5134
812	659344	535387328	28.4956	9.3294	862	743044	640503928	29.3598	9.5171
813	660969	537367797	28.5132	9.3332	863	744769	642735047	29.3769	9.5207
814	662596	539353144	28.5307	9.3370	864	746496	644972544	29.3939	9.5244
815	664225	541333849	28.5482	9.3408	865	748225	647214625	29.4109	9.5281
816	665856	543318406	28.5657	9.3447	866	749956	649461896	29.4279	9.5317
817	667489	545308513	28.5832	9.3485	867	751689	651714363	29.4449	9.5354
818	669124	547343432	28.6007	9.3523	868	753424	653972032	29.4618	9.5391
819	670761	549333259	28.6182	9.3561	869	755161	656234969	29.4788	9.5427
820	672400	551368000	28.6356	9.3599	870	756900	658503000	29.4958	9.5464
821	674041	553387661	28.6531	9.3637	871	758641	660776311	29.5127	9.5501
822	675684	555412248	28.6705	9.3675	872	760384	663054248	29.5296	9.5537
823	677329	557441767	28.6880	9.3713	873	762129	665338617	29.5466	9.5574
824	678976	559476224	28.7054	9.3751	874	763876	667627624	29.5635	9.5610
825	680625	561515625	28.7228	9.3789	875	765625	669921875	29.5804	9.5647
826	682276	563559976	28.7402	9.3827	876	767376	672221376	29.5973	9.5683
827	683929	565609283	28.7576	9.3865	877	769129	674526133	29.6142	9.5719
828	685584	567663552	28.7750	9.3902	878	770884	676836152	29.6311	9.5756
829	687241	569722789	28.7924	9.3940	879	772641	679151439	29.6479	9.5792
830	688900	571787000	28.8097	9.3978	880	774400	681472000	29.6648	9.5828
831	690561	573856191	28.8271	9.4016	881	776161	683797841	29.6816	9.5865
832	692224	575930308	28.8444	9.4053	882	777924	686128968	29.6985	9.5901
833	693889	578009537	28.8617	9.4091	883	779689	688465387	29.7153	9.5937
834	695556	580093704	28.8791	9.4129	884	781456	690807104	29.7321	9.5973
835	697225	582182875	28.8964	9.4166	885	783225	693154125	29.7489	9.6010
836	698896	584277056	28.9137	9.4204	886	784996	695506456	29.7658	9.6046
837	700569	586376253	28.9310	9.4241	887	786769	697864103	29.7825	9.6082
838	702244	588480472	28.9482	9.4279	888	788544	700227072	29.7993	9.6118
839	703921	590589719	28.9655	9.4316	889	790321	702595369	29.8161	9.6154
840	705600	592704000	28.9828	9.4354	890	792100	704969000	29.8329	9.6190
841	707281	594823321	29.0000	9.4391	891	793881	707347971	29.8496	9.6226
842	708964	596947688	29.0172	9.4429	892	795664	709732288	29.8664	9.6262
843	710649	599077107	29.0345	9.4466	893	797449	712121957	29.8831	9.6298
844	712336	601211584	29.0517	9.4503	894	799236	714516084	29.8998	9.6334
845	714025	603351125	29.0689	9.4541	895	801025	716917375	29.9166	9.6370
846	715716	605495736	29.0861	9.4578	896	802816	719323136	29.9333	9.6406
847	717409	607645423	29.1033	9.4615	897	804609	721734273	29.9500	9.6442
848	719104	609800192	29.1204	9.4652	898	806404	724150992	29.9666	9.6477
849	720801	611960049	29.1376	9.4690	899	808201	726572609	29.9833	9.6513
850	722500	614125000	29.1548	9.4727	900	810000	729000000	30.0000	9.6549

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM  
• 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
901	811801	731432701	30.0167	9.6585	951	904401	860085351	30.8383	9.8330
902	813604	733870808	30.0333	9.6620	952	906304	862801408	30.8545	9.8374
903	815400	736314327	30.0500	9.6656	953	908209	865523177	30.8707	9.8408
904	817216	738763264	30.0666	9.6692	954	910116	868250664	30.8869	9.8443
905	819025	741217625	30.0832	9.6727	955	912025	870983875	30.9031	9.8477
906	820836	743677416	30.0998	9.6763	956	913936	873722816	30.9192	9.8511
907	822649	746142643	30.1164	9.6799	957	915849	876467493	30.9354	9.8546
908	824464	748613312	30.1330	9.6834	958	917764	879217912	30.9516	9.8580
909	826281	751089429	30.1496	9.6870	959	919681	881974079	30.9677	9.8614
910	828100	753571000	30.1662	9.6905	960	921600	884736000	30.9839	9.8648
911	829921	756058031	30.1828	9.6941	961	923521	887503681	31.0000	9.8683
912	831744	758550528	30.1993	9.6976	962	925444	890277128	31.0161	9.8717
913	833569	761048497	30.2159	9.7012	963	927369	893056347	31.0322	9.8751
914	835396	763551044	30.2324	9.7047	964	929296	895841344	31.0483	9.8785
915	837225	766060875	30.2490	9.7082	965	931225	898632125	31.0644	9.8819
916	839056	768575296	30.2655	9.7118	966	933156	901428666	31.0805	9.8854
917	840889	771095213	30.2820	9.7153	967	935089	904231063	31.0966	9.8888
918	842724	773620632	30.2985	9.7188	968	937024	907039232	31.1127	9.8922
919	844561	776151559	30.3150	9.7224	969	938961	909853209	31.1288	9.8956
920	846400	778688000	30.3315	9.7259	970	940900	912673000	31.1448	9.8990
921	848241	781229961	30.3480	9.7294	971	942841	915498861	31.1609	9.9024
922	850084	783777448	30.3645	9.7329	972	944784	918330048	31.1769	9.9058
923	851929	786330467	30.3809	9.7364	973	946729	921167317	31.1929	9.9092
924	853776	788889024	30.3974	9.7400	974	948676	924010424	31.2090	9.9126
925	855625	791453125	30.4138	9.7435	975	950625	926859375	31.2250	9.9160
926	857476	794027776	30.4302	9.7470	976	952576	929714176	31.2410	9.9194
927	859329	796597083	30.4467	9.7505	977	954529	932574833	31.2570	9.9227
928	861184	799178752	30.4631	9.7540	978	956484	935441352	31.2730	9.9261
929	863041	801765089	30.4795	9.7575	979	958441	938313739	31.2890	9.9295
930	864900	804357000	30.4959	9.7610	980	960400	941192000	31.3050	9.9329
931	866761	806954401	30.5123	9.7645	981	962361	944076141	31.3209	9.9363
932	868624	809557568	30.5287	9.7680	982	964324	946966168	31.3369	9.9396
933	870489	812166237	30.5450	9.7715	983	966289	949862287	31.3528	9.9430
934	872356	814780504	30.5614	9.7750	984	968256	952763004	31.3688	9.9464
935	874225	817400375	30.5778	9.7785	985	970225	955671625	31.3847	9.9497
936	876096	820028856	30.5941	9.7820	986	972196	958585256	31.4006	9.9531
937	877969	822659653	30.6105	9.7854	987	974169	961504803	31.4166	9.9565
938	879844	825293672	30.6268	9.7889	988	976144	964430272	31.4325	9.9598
939	881721	827930019	30.6431	9.7924	989	978121	967361669	31.4484	9.9632
940	883600	830584000	30.6594	9.7959	990	980100	970299000	31.4643	9.9666
941	885481	833237621	30.6757	9.7993	991	982081	973242271	31.4802	9.9699
942	887364	835896888	30.6920	9.8028	992	984064	976191488	31.4960	9.9733
943	889249	838561807	30.7083	9.8063	993	986049	979146057	31.5119	9.9766
944	891136	841232384	30.7246	9.8097	994	988036	982107784	31.5278	9.9800
945	893025	843908625	30.7409	9.8132	995	990025	985074875	31.5436	9.9833
946	894916	846590536	30.7571	9.8167	996	992016	988047936	31.5595	9.9866
947	896809	849278123	30.7734	9.8201	997	994009	991026973	31.5753	9.9900
948	898704	851971392	30.7896	9.8236	998	996004	994013002	31.5911	9.9933
949	900601	854670349	30.8058	9.8270	999	998001	997002999	31.6070	9.9967
950	902500	857375000	30.8221	9.8305	1000	1000000	1000000000	31.6228	10.0000

## LOGARITHMS OF NUMBERS

N	0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396

This table of logarithms is to the base 10. Napierian logarithms are to a base  $e = 1 + \frac{1}{1 \cdot 2} + \frac{1}{1 \cdot 2 \cdot 3} + \frac{1}{1 \cdot 2 \cdot 3 \cdot 4}$  etc. See footnotes on opposite page.



LOGARITHMS OF NUMBERS. *Concluded*

N .	0	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996

$e = 2.718281828459$ .

$\log_{10} \times 2.30259 = \log e$  (Napierian logarithm)

$\log e \times 0.43429448 = \log_{10}$  (common logarithm).

## NATURAL SINES AND COSINES

NOTE.—For cosines use right-hand column of degrees and lower line of tenths.

Deg.	°0.0	°0.1	°0.2	°0.3	°0.4	°0.5	°0.6	°0.7	°0.8	°0.9	
0°	0.0000	0.0017	0.0035	0.0052	0.0070	0.0087	0.0105	0.0122	0.0140	0.0157	89
1	0.0175	0.0192	0.0209	0.0227	0.0244	0.0262	0.0279	0.0297	0.0314	0.0332	88
2	0.0349	0.0366	0.0384	0.0401	0.0419	0.0436	0.0454	0.0471	0.0488	0.0506	87
3	0.0523	0.0541	0.0558	0.0576	0.0593	0.0610	0.0628	0.0645	0.0663	0.0680	86
4	0.0698	0.0715	0.0732	0.0750	0.0767	0.0785	0.0802	0.0819	0.0837	0.0854	85
5	0.0872	0.0889	0.0906	0.0924	0.0941	0.0958	0.0976	0.0993	0.1011	0.1028	84
6	0.1045	0.1063	0.1080	0.1097	0.1115	0.1132	0.1149	0.1167	0.1184	0.1201	83
7	0.1219	0.1236	0.1253	0.1271	0.1288	0.1305	0.1323	0.1340	0.1357	0.1374	82
8	0.1392	0.1409	0.1426	0.1444	0.1461	0.1478	0.1495	0.1513	0.1530	0.1547	81
9	0.1564	0.1582	0.1599	0.1616	0.1633	0.1650	0.1668	0.1685	0.1702	0.1719	80°
10°	0.1736	0.1754	0.1771	0.1788	0.1805	0.1822	0.1840	0.1857	0.1874	0.1891	79
11	0.1908	0.1925	0.1942	0.1959	0.1977	0.1994	0.2011	0.2028	0.2045	0.2062	78
12	0.2079	0.2096	0.2113	0.2130	0.2147	0.2164	0.2181	0.2198	0.2215	0.2232	77
13	0.2250	0.2267	0.2284	0.2300	0.2317	0.2334	0.2351	0.2368	0.2385	0.2402	76
14	0.2419	0.2436	0.2453	0.2470	0.2487	0.2504	0.2521	0.2538	0.2554	0.2571	75
15	0.2588	0.2605	0.2622	0.2639	0.2656	0.2672	0.2689	0.2706	0.2723	0.2740	74
16	0.2756	0.2773	0.2790	0.2807	0.2823	0.2840	0.2857	0.2874	0.2890	0.2907	73
17	0.2924	0.2940	0.2957	0.2974	0.2990	0.3007	0.3024	0.3040	0.3057	0.3074	72
18	0.3090	0.3107	0.3123	0.3140	0.3156	0.3173	0.3190	0.3206	0.3223	0.3239	71
19	0.3256	0.3272	0.3289	0.3305	0.3322	0.3338	0.3355	0.3371	0.3387	0.3404	70°
20°	0.3420	0.3437	0.3453	0.3469	0.3486	0.3502	0.3518	0.3535	0.3551	0.3567	69
21	0.3584	0.3600	0.3616	0.3633	0.3649	0.3665	0.3681	0.3697	0.3714	0.3730	68
22	0.3746	0.3762	0.3778	0.3795	0.3811	0.3827	0.3843	0.3859	0.3875	0.3891	67
23	0.3907	0.3923	0.3939	0.3955	0.3971	0.3987	0.4003	0.4019	0.4035	0.4051	66
24	0.4067	0.4083	0.4099	0.4115	0.4131	0.4147	0.4163	0.4179	0.4195	0.4210	65
25	0.4226	0.4242	0.4258	0.4274	0.4289	0.4305	0.4321	0.4337	0.4352	0.4368	64
26	0.4384	0.4399	0.4415	0.4431	0.4446	0.4462	0.4478	0.4493	0.4509	0.4524	63
27	0.4540	0.4555	0.4571	0.4586	0.4602	0.4617	0.4633	0.4648	0.4664	0.4679	62
28	0.4695	0.4710	0.4726	0.4741	0.4756	0.4772	0.4787	0.4802	0.4818	0.4833	61
29	0.4848	0.4863	0.4879	0.4894	0.4909	0.4924	0.4939	0.4955	0.4970	0.4985	60°
30°	0.5000	0.5015	0.5030	0.5045	0.5060	0.5075	0.5090	0.5105	0.5120	0.5135	59
31	0.5150	0.5165	0.5180	0.5195	0.5210	0.5225	0.5240	0.5255	0.5270	0.5284	58
32	0.5299	0.5314	0.5329	0.5344	0.5358	0.5373	0.5388	0.5402	0.5417	0.5432	57
33	0.5446	0.5461	0.5476	0.5490	0.5505	0.5519	0.5534	0.5548	0.5563	0.5577	56
34	0.5592	0.5606	0.5621	0.5635	0.5650	0.5664	0.5678	0.5693	0.5707	0.5721	55
35	0.5736	0.5750	0.5764	0.5779	0.5793	0.5807	0.5821	0.5835	0.5850	0.5864	54
36	0.5878	0.5892	0.5906	0.5920	0.5934	0.5948	0.5962	0.5976	0.5990	0.6004	53
37	0.6018	0.6032	0.6046	0.6060	0.6074	0.6088	0.6101	0.6115	0.6129	0.6143	52
38	0.6157	0.6170	0.6184	0.6198	0.6211	0.6225	0.6239	0.6252	0.6266	0.6280	51
39	0.6293	0.6307	0.6320	0.6334	0.6347	0.6361	0.6374	0.6388	0.6401	0.6414	50°
40°	0.6428	0.6441	0.6455	0.6468	0.6481	0.6494	0.6508	0.6521	0.6534	0.6547	49
41	0.6561	0.6574	0.6587	0.6600	0.6613	0.6626	0.6639	0.6652	0.6665	0.6678	48
42	0.6691	0.6704	0.6717	0.6730	0.6743	0.6756	0.6769	0.6782	0.6794	0.6807	47
43	0.6820	0.6833	0.6845	0.6858	0.6871	0.6884	0.6896	0.6909	0.6921	0.6934	46
44	0.6947	0.6959	0.6972	0.6984	0.6997	0.7009	0.7022	0.7034	0.7046	0.7059	45
	°1.0	°0.9	°0.8	°0.7	°0.6	°0.5	°0.4	°0.3	°0.2	°0.1	Deg.

NATURAL SINES AND COSINES. *Concluded*

Deg.	°0.0	°0.1	°0.2	°0.3	°0.4	°0.5	°0.6	°0.7	°0.8	°0.9	
45	0.7071	0.7083	0.7096	0.7108	0.7120	0.7133	0.7145	0.7157	0.7169	0.7181	44
46	0.7193	0.7206	0.7218	0.7230	0.7242	0.7254	0.7266	0.7278	0.7290	0.7302	43
47	0.7314	0.7325	0.7337	0.7349	0.7361	0.7373	0.7385	0.7396	0.7408	0.7420	42
48	0.7431	0.7443	0.7455	0.7466	0.7478	0.7490	0.7501	0.7513	0.7524	0.7536	41
49	0.7547	0.7559	0.7570	0.7581	0.7593	0.7604	0.7615	0.7627	0.7638	0.7649	40°
50°	0.7660	0.7672	0.7683	0.7694	0.7705	0.7716	0.7727	0.7738	0.7749	0.7760	39
51	0.7771	0.7782	0.7793	0.7804	0.7815	0.7826	0.7837	0.7848	0.7859	0.7869	38
52	0.7880	0.7891	0.7902	0.7912	0.7923	0.7934	0.7944	0.7955	0.7965	0.7976	37
53	0.7986	0.7997	0.8007	0.8018	0.8028	0.8039	0.8049	0.8059	0.8070	0.8080	36
54	0.8090	0.8100	0.8111	0.8121	0.8131	0.8141	0.8151	0.8161	0.8171	0.8181	35
55	0.8192	0.8202	0.8211	0.8221	0.8231	0.8241	0.8251	0.8261	0.8271	0.8281	34
56	0.8290	0.8300	0.8310	0.8320	0.8329	0.8339	0.8348	0.8358	0.8368	0.8377	33
57	0.8387	0.8396	0.8406	0.8415	0.8425	0.8434	0.8443	0.8453	0.8462	0.8471	32
58	0.8480	0.8490	0.8499	0.8508	0.8517	0.8526	0.8536	0.8545	0.8554	0.8563	31
59	0.8572	0.8581	0.8590	0.8599	0.8607	0.8616	0.8625	0.8634	0.8643	0.8652	30°
60°	0.8660	0.8669	0.8678	0.8686	0.8695	0.8704	0.8712	0.8721	0.8729	0.8738	29
61	0.8746	0.8755	0.8763	0.8771	0.8780	0.8788	0.8796	0.8805	0.8813	0.8821	28
62	0.8829	0.8838	0.8846	0.8854	0.8862	0.8870	0.8878	0.8886	0.8894	0.8902	27
63	0.8910	0.8918	0.8926	0.8934	0.8942	0.8949	0.8957	0.8965	0.8973	0.8980	26
64	0.8988	0.8996	0.9003	0.9011	0.9018	0.9026	0.9033	0.9041	0.9048	0.9056	25
65	0.9063	0.9070	0.9078	0.9085	0.9092	0.9100	0.9107	0.9114	0.9121	0.9128	24
66	0.9135	0.9143	0.9150	0.9157	0.9164	0.9171	0.9178	0.9184	0.9191	0.9198	23
67	0.9205	0.9212	0.9219	0.9225	0.9232	0.9239	0.9245	0.9252	0.9259	0.9265	22
68	0.9272	0.9278	0.9285	0.9291	0.9298	0.9304	0.9311	0.9317	0.9323	0.9330	21
69	0.9336	0.9342	0.9348	0.9354	0.9361	0.9367	0.9373	0.9379	0.9385	0.9391	20°
70°	0.9397	0.9403	0.9409	0.9415	0.9421	0.9426	0.9432	0.9438	0.9444	0.9449	19
71	0.9455	0.9461	0.9466	0.9472	0.9478	0.9483	0.9489	0.9494	0.9500	0.9505	18
72	0.9511	0.9516	0.9521	0.9527	0.9532	0.9537	0.9542	0.9548	0.9553	0.9558	17
73	0.9563	0.9568	0.9573	0.9578	0.9583	0.9588	0.9593	0.9598	0.9603	0.9608	16
74	0.9613	0.9617	0.9622	0.9627	0.9632	0.9636	0.9641	0.9646	0.9650	0.9655	15
75	0.9659	0.9664	0.9668	0.9673	0.9677	0.9681	0.9686	0.9690	0.9694	0.9699	14
76	0.9703	0.9707	0.9711	0.9715	0.9720	0.9724	0.9728	0.9732	0.9736	0.9740	13
77	0.9744	0.9748	0.9751	0.9755	0.9759	0.9763	0.9767	0.9770	0.9774	0.9778	12
78	0.9781	0.9785	0.9789	0.9792	0.9796	0.9799	0.9803	0.9806	0.9810	0.9813	11
79	0.9816	0.9820	0.9823	0.9826	0.9829	0.9833	0.9836	0.9839	0.9842	0.9845	10°
80°	0.9848	0.9851	0.9854	0.9857	0.9860	0.9863	0.9866	0.9869	0.9871	0.9874	9
81	0.9877	0.9880	0.9882	0.9885	0.9888	0.9890	0.9893	0.9895	0.9898	0.9900	8
82	0.9903	0.9905	0.9907	0.9910	0.9912	0.9914	0.9917	0.9919	0.9921	0.9923	7
83	0.9925	0.9928	0.9930	0.9932	0.9934	0.9936	0.9938	0.9940	0.9942	0.9943	6
84	0.9945	0.9947	0.9949	0.9951	0.9952	0.9954	0.9956	0.9957	0.9959	0.9960	5
85	0.9962	0.9963	0.9965	0.9966	0.9968	0.9969	0.9971	0.9972	0.9973	0.9974	4
86	0.9976	0.9977	0.9978	0.9979	0.9980	0.9981	0.9982	0.9983	0.9984	0.9985	3
87	0.9986	0.9987	0.9988	0.9989	0.9990	0.9990	0.9991	0.9992	0.9993	0.9993	2
88	0.9994	0.9995	0.9995	0.9996	0.9996	0.9997	0.9997	0.9997	0.9998	0.9998	1
89	0.9998	0.9999	0.9999	0.9999	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	0°
	°1.0	°0.9	°0.8	°0.7	°0.6	°0.5	°0.4	°0.3	°0.2	°0.1	Deg.

NOTE.—For cosines use right-hand column of degrees and lower line of tenths.

# 46 METALLURGISTS AND CHEMISTS' HANDBOOK

## NATURAL TANGENTS AND COTANGENTS

NOTE.—For cotangents use right-hand column of degrees and lower line of tenths

Deg.	°0.0	°0.1	°0.2	°0.3	°0.4	°0.5	°0.6	°0.7	°0.8	°0.9	
0°	0.0000	0.0017	0.0035	0.0052	0.0070	0.0087	0.0105	0.0122	0.0140	0.0157	89
1	0.0175	0.0192	0.0209	0.0227	0.0244	0.0262	0.0279	0.0297	0.0314	0.0332	88
2	0.0349	0.0367	0.0384	0.0402	0.0419	0.0437	0.0454	0.0472	0.0489	0.0507	87
3	0.0524	0.0542	0.0559	0.0577	0.0594	0.0612	0.0629	0.0647	0.0664	0.0682	86
4	0.0699	0.0717	0.0734	0.0752	0.0769	0.0787	0.0805	0.0822	0.0840	0.0857	85
5	0.0875	0.0892	0.0910	0.0928	0.0945	0.0963	0.0981	0.0998	0.1016	0.1033	84
6	0.1051	0.1069	0.1086	0.1104	0.1122	0.1139	0.1157	0.1175	0.1192	0.1210	83
7	0.1228	0.1246	0.1263	0.1281	0.1299	0.1317	0.1334	0.1352	0.1370	0.1388	82
8	0.1405	0.1423	0.1441	0.1459	0.1477	0.1495	0.1512	0.1530	0.1548	0.1566	81
9	0.1584	0.1602	0.1620	0.1638	0.1655	0.1673	0.1691	0.1709	0.1727	0.1745	80°
10°	0.1763	0.1781	0.1799	0.1817	0.1835	0.1853	0.1871	0.1890	0.1908	0.1926	79
11	0.1944	0.1962	0.1980	0.1998	0.2016	0.2035	0.2053	0.2071	0.2089	0.2107	78
12	0.2126	0.2144	0.2162	0.2180	0.2199	0.2217	0.2235	0.2254	0.2272	0.2290	77
13	0.2309	0.2327	0.2345	0.2364	0.2382	0.2401	0.2419	0.2438	0.2456	0.2475	76
14	0.2493	0.2512	0.2530	0.2549	0.2568	0.2586	0.2605	0.2623	0.2642	0.2661	75
15	0.2679	0.2698	0.2717	0.2736	0.2754	0.2773	0.2792	0.2811	0.2830	0.2849	74
16	0.2867	0.2886	0.2905	0.2924	0.2943	0.2962	0.2981	0.3000	0.3019	0.3038	73
17	0.3057	0.3076	0.3096	0.3115	0.3134	0.3153	0.3172	0.3191	0.3211	0.3230	72
18	0.3249	0.3269	0.3288	0.3307	0.3327	0.3346	0.3365	0.3385	0.3404	0.3424	71
19	0.3443	0.3463	0.3482	0.3502	0.3522	0.3541	0.3561	0.3581	0.3600	0.3620	70°
20°	0.3640	0.3659	0.3679	0.3699	0.3719	0.3739	0.3759	0.3779	0.3799	0.3819	69
21	0.3839	0.3859	0.3879	0.3899	0.3919	0.3939	0.3959	0.3979	0.4000	0.4020	68
22	0.4040	0.4061	0.4081	0.4101	0.4122	0.4142	0.4163	0.4183	0.4204	0.4224	67
23	0.4245	0.4265	0.4286	0.4307	0.4327	0.4348	0.4369	0.4390	0.4411	0.4431	66
24	0.4452	0.4473	0.4494	0.4515	0.4536	0.4557	0.4578	0.4599	0.4621	0.4642	65
25	0.4663	0.4684	0.4706	0.4727	0.4748	0.4770	0.4791	0.4813	0.4834	0.4856	64
26	0.4877	0.4899	0.4921	0.4942	0.4964	0.4986	0.5008	0.5029	0.5051	0.5073	63
27	0.5095	0.5117	0.5139	0.5161	0.5184	0.5206	0.5228	0.5250	0.5272	0.5295	62
28	0.5317	0.5340	0.5362	0.5384	0.5407	0.5430	0.5452	0.5475	0.5498	0.5520	61
29	0.5543	0.5566	0.5589	0.5612	0.5635	0.5658	0.5681	0.5704	0.5727	0.5750	60°
30°	0.5774	0.5797	0.5820	0.5844	0.5867	0.5890	0.5914	0.5938	0.5961	0.5985	59
31	0.6009	0.6032	0.6056	0.6080	0.6104	0.6128	0.6152	0.6176	0.6200	0.6224	58
32	0.6249	0.6273	0.6297	0.6322	0.6346	0.6371	0.6395	0.6420	0.6445	0.6469	57
33	0.6494	0.6519	0.6544	0.6569	0.6594	0.6619	0.6644	0.6669	0.6694	0.6720	56
34	0.6745	0.6771	0.6796	0.6822	0.6847	0.6873	0.6899	0.6924	0.6950	0.6976	55
35	0.7002	0.7028	0.7054	0.7080	0.7107	0.7133	0.7159	0.7186	0.7212	0.7239	54
36	0.7265	0.7292	0.7319	0.7346	0.7373	0.7400	0.7427	0.7454	0.7481	0.7508	53
37	0.7536	0.7563	0.7590	0.7618	0.7646	0.7673	0.7701	0.7729	0.7757	0.7785	52
38	0.7813	0.7841	0.7869	0.7898	0.7926	0.7954	0.7983	0.8012	0.8040	0.8069	51
39	0.8098	0.8127	0.8156	0.8185	0.8214	0.8243	0.8273	0.8302	0.8332	0.8361	50°
40°	0.8391	0.8421	0.8451	0.8481	0.8511	0.8541	0.8571	0.8601	0.8632	0.8662	49
41	0.8693	0.8724	0.8754	0.8785	0.8816	0.8847	0.8878	0.8910	0.8941	0.8972	48
42	0.9004	0.9036	0.9067	0.9099	0.9131	0.9163	0.9195	0.9228	0.9260	0.9293	47
43	0.9325	0.9358	0.9391	0.9424	0.9457	0.9490	0.9523	0.9556	0.9590	0.9623	46
44	0.9657	0.9691	0.9725	0.9759	0.9793	0.9827	0.9861	0.9896	0.9930	0.9965	45
	°1.0	°0.9	°0.8	°0.7	°0.6	°0.5	°0.4	°0.3	°0.2	°0.1	Deg.

NATURAL TANGENTS AND COTANGENTS. *Concluded*

Deg	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	
45	1.0000	1.0035	1.0070	1.0105	1.0141	1.0176	1.0212	1.0247	1.0283	1.0319	44
46	1.0355	1.0392	1.0428	1.0464	1.0501	1.0538	1.0575	1.0612	1.0649	1.0686	43
47	1.0724	1.0761	1.0799	1.0837	1.0875	1.0913	1.0951	1.0990	1.1028	1.1067	42
48	1.1106	1.1145	1.1184	1.1224	1.1263	1.1303	1.1343	1.1383	1.1423	1.1463	41
49	1.1504	1.1544	1.1585	1.1626	1.1667	1.1708	1.1750	1.1792	1.1833	1.1875	40°
50°	1.1918	1.1960	1.2002	1.2045	1.2088	1.2131	1.2174	1.2218	1.2261	1.2305	39
51	1.2349	1.2393	1.2437	1.2482	1.2527	1.2572	1.2617	1.2662	1.2708	1.2753	38
52	1.2799	1.2846	1.2892	1.2938	1.2985	1.3032	1.3079	1.3127	1.3175	1.3222	37
53	1.3270	1.3319	1.3367	1.3416	1.3465	1.3514	1.3564	1.3613	1.3663	1.3713	36
54	1.3764	1.3814	1.3865	1.3916	1.3968	1.4019	1.4071	1.4124	1.4176	1.4229	35
55	1.4281	1.4335	1.4388	1.4442	1.4496	1.4550	1.4605	1.4659	1.4715	1.4770	34
56	1.4826	1.4882	1.4938	1.4994	1.5051	1.5108	1.5166	1.5224	1.5282	1.5340	33
57	1.5399	1.5458	1.5517	1.5577	1.5637	1.5697	1.5757	1.5818	1.5880	1.5941	32
58	1.6003	1.6066	1.6128	1.6191	1.6255	1.6319	1.6383	1.6447	1.6512	1.6577	31
59	1.6643	1.6709	1.6775	1.6842	1.6909	1.6977	1.7045	1.7113	1.7182	1.7251	30°
60°	1.7321	1.7391	1.7461	1.7532	1.7603	1.7675	1.7747	1.7820	1.7893	1.7966	29
61	1.8040	1.8115	1.8190	1.8265	1.8341	1.8418	1.8495	1.8572	1.8650	1.8728	28
62	1.8807	1.8887	1.8967	1.9047	1.9128	1.9210	1.9292	1.9375	1.9458	1.9542	27
63	1.9626	1.9711	1.9797	1.9883	1.9970	2.0057	2.0145	2.0233	2.0323	2.0413	26
64	2.0503	2.0599	2.0696	2.0792	2.0872	2.0965	2.1060	2.1155	2.1251	2.1348	25
65	2.1445	2.1543	2.1642	2.1742	2.1842	2.1943	2.2045	2.2148	2.2251	2.2355	24
66	2.2460	2.2566	2.2673	2.2781	2.2889	2.2998	2.3109	2.3220	2.3332	2.3445	23
67	2.3559	2.3673	2.3789	2.3906	2.4023	2.4142	2.4262	2.4383	2.4504	2.4627	22
68	2.4751	2.4876	2.5002	2.5129	2.5257	2.5386	2.5517	2.5649	2.5782	2.5916	21
69	2.6051	2.6187	2.6325	2.6464	2.6605	2.6746	2.6889	2.7034	2.7179	2.7326	20°
70°	2.7475	2.7625	2.7776	2.7929	2.8083	2.8239	2.8397	2.8556	2.8716	2.8878	19
71	2.9042	2.9208	2.9375	2.9544	2.9714	2.9887	3.0061	3.0237	3.0415	3.0595	18
72	3.0777	3.0961	3.1146	3.1334	3.1524	3.1716	3.1910	3.2106	3.2305	3.2506	17
73	3.2709	3.2914	3.3122	3.3332	3.3544	3.3759	3.3977	3.4197	3.4420	3.4646	16
74	3.4874	3.5105	3.5339	3.5576	3.5816	3.6059	3.6305	3.6554	3.6806	3.7062	15
75	3.7321	3.7583	3.7848	3.8118	3.8391	3.8667	3.8947	3.9232	3.9520	3.9812	14
76	4.0108	4.0408	4.0713	4.1022	4.1335	4.1653	4.1976	4.2303	4.2635	4.2972	13
77	4.3315	4.3662	4.4015	4.4374	4.4737	4.5107	4.5483	4.5864	4.6252	4.6646	12
78	4.7046	4.7453	4.7867	4.8288	4.8716	4.9152	4.9594	5.0045	5.0504	5.0970	11
79	5.1446	5.1929	5.2422	5.2924	5.3435	5.3955	5.4486	5.5026	5.5578	5.6140	10°
80°	5.6713	5.7297	5.7894	5.8502	5.9124	5.9758	6.0405	6.1066	6.1742	6.2432	9
81	6.3133	6.3859	6.4596	6.5350	6.6122	6.6912	6.7720	6.8548	6.9395	7.0264	8
82	7.1154	7.2066	7.3002	7.3962	7.4947	7.5958	7.6996	7.8062	7.9158	8.0285	7
83	8.1443	8.2636	8.3863	8.5126	8.6427	8.7769	8.9152	9.0579	9.2052	9.3572	6
84	9.5144	9.6777	9.845	10.02	10.20	10.39	10.58	10.78	10.99	11.20	5
85	11.43	11.66	11.91	12.16	12.43	12.71	13.00	13.30	13.62	13.95	4
86	14.30	14.67	15.06	15.46	15.89	16.35	16.83	17.34	17.89	18.46	3
87	19.08	19.74	20.45	21.20	22.02	22.90	23.86	24.90	26.03	27.27	2
88	28.64	30.14	31.82	33.69	35.80	38.19	40.92	44.07	47.74	52.08	1
89	57.29	63.66	71.62	81.85	95.49	114.6	143.2	191.0	256.5	573.0	0°
	0.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	Deg.

NOTE.—For cotangents use right-hand column of degrees and lower line of tenths.

## ANALYTIC GEOMETRY

**The Straight Line.**—The equation of the straight line in its simplest form is  $\frac{x}{a} + \frac{y}{b} = 1$ , where  $a$  and  $b$  are the intercepts of the line on the axes of  $X$  and  $Y$  respectively.

The other useful equations of the straight line are:  $y = mx + b$ , where  $m$  is the tangent which the line makes with the axis of  $X$ . The equation of a line passing through a given point  $(x_1, y_1)$  is  $y - y_1 = m(x - x_1)$  where  $m$  is entirely indeterminate, since any number of lines may pass through a point. The equation of a line passing through two points is

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1)$$

The distance between two points  $x_1, y_1$  and  $x_2, y_2$  is:

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Distance from a point  $x_1, y_1$  to a line  $ax + by + c = 0$  is:

$$d = \frac{ax_1 + by_1 + c}{\sqrt{a^2 + b^2}}$$

The equation of an angle  $\Phi$  between two lines  $y = mx + b$  and  $y = m'x + b'$  is:

$$\tan \Phi = \frac{m' - m}{1 + mm'}$$

**The Circle.**—The circle is the locus of all points in a plane equidistant from a given point.

The equation of a circle whose center lies at the origin is:

$$x^2 + y^2 = r^2$$

If its center lies at  $(a, b)$ :

$$(x - a)^2 + (y - b)^2 = r^2$$

If the origin lies on the left extremity of the diameter, the equation is:

$$(x - r)^2 + (y - 0)^2 = r^2 \text{ (as above)}$$

or simplifying

$$y^2 = 2xr - x^2$$

**The Ellipse.**—The ellipse is the locus of a point moving in a plane so that the sum of its distances from two points in the plane is a constant. The ratio of the constant sum (the major diameter) to the distance between the foci is known as the eccentricity,  $e$ .

The area of an ellipse =  $\pi$  times the product of the semi-diameters.

The equation of the ellipse is

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \text{ (center at the origin)}$$

The tangent to the above ellipse through the point of tangency  $x_1, y_1$  is

$$\frac{xx_1}{a^2} + \frac{yy_1}{b^2} = 1$$

**The Parabola.**—The parabola is the locus of a point moving in a plane so that its distance from a point (the focus) in the plane is always equal to its distance from a line (the directrix) in the plane. Its equation, the curve passing through the origin and its focus lying on the axis of  $X$  is  $y^2 = 4px$ , polar coordinates  $\rho = p \sec^2 \frac{\theta}{2}$ , where  $4p$  is the double ordinate through the focus. A tangent to a parabola through the point of tangency  $x_1, y_1$ , is  $yy_1 = p(x + x_1)$ .

The tangent at any point makes equal angles with the axis and a line from the point of tangency to the focus. The parabola has no finite asymptotes.

**The Hyperbola.**—The hyperbola is the locus of a point moving in a plane so that the differences of its distances from two fixed points in the plane is a constant. Its equation, with its center at the origin and its foci on the axis of  $x$  is

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$$

Equilateral hyperbola:  $x^2 - y^2 = a^2$ .

Equilateral hyperbola referred to its axes as asymptotes:  $xy = c^2$  (This is the isothermal curve of pressure and volume in gases).

Equation of the asymptotes

$$\frac{x}{a} = \frac{y}{b}, \frac{x}{a} = -\frac{y}{b}$$

The tangent to a hyperbola bisects the angle formed by the two lines drawn from the point of tangency to the foci.

**The Cycloid.**—The cycloid is the curve generated by a point in the circumference of a circle rolling on a straight line. It consists of an infinite number of equal arches.

$$\left. \begin{aligned} x &= a \cos^{-1} \frac{a-y}{a} - \sqrt{2ay - y^2} \text{ or } x = a(\theta - \sin \theta) \\ y &= a(1 - \cos \theta) \end{aligned} \right\}$$

**The Epicycloid and Hypocycloid.**—The epicycloid is generated by a point in the circumference of a circle rolling upon another circle. The hypocycloid is the curve generated by a point on the circumference of a circle rolling inside another circle.

$$\text{Epicycloid} \quad \left\{ \begin{aligned} x &= (a+b) \cos \theta - b \cos \frac{a+b}{b} \theta \\ y &= (a+b) \sin \theta - b \sin \frac{a+b}{b} \theta \end{aligned} \right.$$

$$\text{Hypocycloid} \quad \left\{ \begin{aligned} x &= (a-b) \cos \theta + b \cos \frac{a-b}{b} \theta \\ y &= (a-b) \sin \theta - b \sin \frac{a-b}{b} \theta \end{aligned} \right.$$

where  $a$  is the radius of the main circle, and  $b$  of the generating circle.

**Cubical Parabola.**—Formula,  $a^2y = x^3$ .

**Semicubical Parabola.**—Formula,  $ay^2 = x^3$ .

**Witch of Agnesi.**—Formula,  $y = \frac{8a^3}{x^2 + 4a^2}$ .

**Cissoid of Diocles.**—Formula,  $y^2 = \frac{x^3}{2a - x}$ .

$$\rho = 2a \tan \theta \sin \theta.$$

This and the conchoid were invented to solve the problems of the duplication of the cube, *i.e.*, given a cube,  $a^3$ , whose side is  $a$ , to construct the side of a cube,  $2a^3$ .

**Lemniscate of Bernoulli.**—Formula,  $(x^2 + y^2)^2 = a^2(x^2 - y^2)$   
 $\rho^2 = a^2 \cos \theta$ .

This and the following have a singular point at 0, 0.

**Strophoid.**—Formula,  $y^2 = x^2 \left( \frac{a - x}{a + x} \right)$

$$\rho = a(\cos \theta - \sin \theta \tan \theta).$$

**Cardioid.**—Formula,  $x^2 + y^2 + ax = a\sqrt{x^2 + y^2}$

$$\begin{cases} x = a \cos \theta (1 - \cos \theta) \\ y = a \sin \theta (1 - \cos \theta) \\ \rho = a(1 - \cos \theta) \end{cases}$$

This is a special case of the epicycloid in which the generating circles are equal.

**The Probability Curve.**—Formula,  $y = e^{-x^2}$ .

**The Catenary.**—The catenary is the curve assumed by a uniform, completely flexible cord supported at its two ends. Its equation is

$$y = \frac{a}{2} (e^{\frac{x}{a}} + e^{-\frac{x}{a}})$$

where  $e$  is the base of the Napierian system of logarithms.

**The Involute.**—The involute is the curve described by a point in a string which is being kept taut and unwound from a cylinder.

$$\begin{cases} x = a(\cos \theta + \theta \sin \theta) \\ y = a(\sin \theta + \theta \cos \theta) \end{cases}$$

or

$$\theta = \frac{\sqrt{\rho^2 - a^2}}{a} - \tan^{-1} \frac{\sqrt{\rho^2 - a^2}}{a}.$$

**The Spiral of Archimedes** is a curve described by the extremity of a radius vector which lengthens in proportion to the angle traversed. That is, the turns are equidistant from each other.

$$\rho = a\theta$$

**Hyperbolic Spiral.**—Formula,  $\rho\theta = a$ .

**Logarithmic Spiral.**—Formula,  $\rho = e^{a\theta}$ .

**Lituus.**—Formula,  $\rho^2\theta = a^3$ .

## CALCULUS

### Elementary Differentials

$$\frac{d(c)}{dx} = 0$$

$$\frac{d(x)}{dx} = 1$$

$$\frac{d(cu)}{dx} = cu$$



$$d(cx) = c$$

$$d(u \pm v \pm w \dots) = du \pm dv \pm dw \dots$$

$$d(uv) = vdu + u dv$$

$$d(uvw) = vwd u + vdw + uwdv$$

$$\frac{d(uvw)}{uvw} = \frac{du}{u} + \frac{dv}{v} + \frac{dw}{w}$$

$$d(u^n) = nu^{n-1}du; d(x^n) = nx^{n-1}$$

$$d\left(\frac{u}{v}\right) = \frac{vdu - u dv}{v^2}; d\left(\frac{1}{v}\right) = \frac{dv}{v^2}; d\left(\frac{1}{x}\right) = -\frac{1}{x^2}$$

$$d(\sin x) = \cos x$$

$$d(\tan x) = \sec^2 x$$

$$d(\sec x) = \sec x \tan x$$

$$d(\cos x) = -\sin x$$

$$d(\cot x) = -\csc^2 x$$

$$d(\csc x) = -\csc x \cot x$$

$$d \sin^{-1} u = \frac{du}{\sqrt{1-u^2}}$$

$$d \tan^{-1} u = \frac{du}{1+u^2}$$

$$d \sec^{-1} u = \frac{du}{u\sqrt{u^2-1}}$$

$$d \cos^{-1} u = -\frac{du}{\sqrt{1-u^2}}$$

$$d \cot^{-1} u = -\frac{du}{1+u^2}$$

$$d \csc^{-1} u = -\frac{du}{u\sqrt{u^2-1}}$$

$$d \log_a u = \log_a e \cdot \frac{du}{u}; d \log_a x = \log_a e = \frac{1}{x}$$

$$d \log_e u = \frac{du}{u}$$

$$da^u = a^u \log_e a du$$

$$de^u = e^u du$$

### Fundamental Integrals<sup>1</sup>

$$\int a dx = ax$$

$$\int af(x)dx = a \int f(x)dx$$

$$\int \frac{dx}{x} = \log x$$

$$\int x^m dx = \frac{x^{m+1}}{m+1}, \text{ when } m \text{ is different from } -1$$

$$\int e^x dx = e^x$$

$$\int a^x \log a dx = a^x$$

$$\int \frac{dx}{1+x^2} = \tan^{-1} x$$

$$\int \frac{dx}{\sqrt{1-x^2}} = \sin^{-1} x$$

$$\int \frac{dx}{x\sqrt{x^2-1}} = \sec^{-1} x$$

$$\int \frac{dx}{\sqrt{2x-x^2}} = \text{vers}^{-1} x$$

<sup>1</sup> For the more complicated integrals, see B. O. PIERCE'S "Short Table of Integrals" and the various works on integral calculus.

$$\int \cos x dx = \sin x$$

$$\int \sin x dx = -\cos x$$

$$\int \cot x dx = \log \sin x$$

$$\int \tan x dx = -\log \sin x$$

$$\int \tan x \sec x dx = \sec x$$

$$\int \sec^2 x dx = \tan x$$

$$\int \csc^2 x dx = -\cot x$$

$$\int [f(x) + \varphi(x) + \psi(x)] dx = \int f(x) dx + \int \varphi(x) dx + \int \psi(x) dx$$

$$\int u dv = uv - \int v du \text{ where } u \text{ and } v \text{ are functions of } x$$

$$\int u \frac{dv}{dx} dx = uv - \int v \frac{du}{dx} dx$$

$$\int f(y) \frac{dy}{dx} dx = \int f(y) dy$$

$$\int \sin^2 x dx = -\frac{1}{2} \cos x \sin x + \frac{1}{2} x$$

$$\int \sin^3 x dx = -\frac{1}{3} \cos x (\sin^2 x + 2)$$

$$\int \sin^n x dx = -\frac{\sin^{n-1} x \cos x}{n} + \frac{n-1}{n} \int \sin^{n-2} x dx$$

$$\int \cos^2 x dx = \frac{1}{2} \sin x \cos x + \frac{1}{2} x$$

$$\int \cos^3 x dx = \frac{1}{3} \sin x (\cos^2 x + 2)$$

$$\int \cos^n x dx = \frac{\cos^{n-1} x \sin x}{n} + \frac{n-1}{n} \int \cos^{n-2} x dx$$

$$\int \sin x \cos x dx = \frac{1}{2} \sin^2 x$$

$$\int \tan^2 x dx = \tan x - x$$

$$\int \tan^n x dx = \frac{\tan^{n-1} x}{n-1} - \int \tan^{n-2} x dx$$

$$\int \cot^2 x dx = -\cot x - x$$

$$\int \cot^n x dx = -\frac{\cot^{n-2} x}{n-1} - \int \cot^{n-2} x dx$$

$$\int \sin^{-1} x dx = x \sin^{-1} x + \sqrt{1-x^2}$$

$$\int \cos^{-1} x dx = x \cos^{-1} x - \sqrt{1-x^2}$$

$$\int \tan^{-1} x dx = x \tan^{-1} x - \frac{1}{2} \log(1+x^2)$$

$$\int \cot^{-1} x dx = x \cot^{-1} x + \frac{1}{2} \log(1+x^2)$$

$$\int e^{ax} dx = \frac{e^{ax}}{a}$$

$$e = 2.718281828459$$

$$\log_e x = 2.3025851 \log_{10} x$$

## SECTION II

### METALLURGICAL PRICE AND PRODUCTION STATISTICS.

#### Metal Prices

For the current figures on metal prices it is, of course, necessary to refer to the "Engineering and Mining Journal." But it is often convenient to have the figures for some years back, for instance in computing mine valuations, or in calculations on metallurgical processes where the value of a metal over a term of years enters into the problem. For that reason I have introduced the following tables.

#### AVERAGE PRICES OF IRON, QUICKSILVER, ANTIMONY AND PLATINUM

	Iron, basic pig, valley furnaces per gross ton	Quicksilver, dollars per flask (flask = 75 lb.), N. Y.	Antimony, cents per pound, ordinaries	Platinum, dollars per ounce, N. Y.
1915	14.71	87.01	30.280	47.13
1916	19.87	125.49	25.370	83.40
1917	38.52	106.30	20.690	102.82
1918	32.50	123.47	12.581	105.95
1919	27.88	92.15	8.190	114.61
1920	41.40	81.12	8.485	110.90
1921	21.07	45.46	4.957	75.03
1922	24.43	58.946	5.471	97.618
1923	25.87	66.502	7.897	116.537
1924	20.29	69.761	10.836	118.817
1925	19.70	83.123	17.494	119.093
1926	19.30	91.903	15.988	113.269
1927	17.76	118.159	42.393	84.636
1928	16.65	123.506	10.305	78.580

# 54 METALLURGISTS AND CHEMISTS' HANDBOOK

## MONTHLY PRICES OF ELECTROLYTIC COPPER AT NEW YORK FOR 20 YEARS

(In Cents per Pound)

	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917
Jan.....	13.726	13.893	13.620	12.295	14.094	16.488	14.223	13.641	24.008	28.673
Feb. ....	12.905	12.949	13.332	12.256	14.084	14.971	14.491	14.394	26.440	31.750
March.....	12.704	12.387	13.255	12.139	14.698	14.713	14.131	14.787	26.310	31.481
April .....	12.743	12.562	12.733	12.019	15.741	15.291	14.211	16.811	27.895	27.935
May .....	12.598	12.893	12.550	11.989	16.031	15.436	13.996	18.506	28.625	28.788
June .....	12.675	13.214	12.404	12.385	17.234	14.672	13.603	19.477	26.601	29.962
July .....	12.702	12.880	12.215	12.463	17.190	14.190	13.223	18.796	23.865	26.620
Aug .....	13.462	13.007	12.400	12.405	17.498	15.400	<sup>1</sup>	16.941	26.120	25.380
Sept. ....	13.388	12.870	12.379	12.201	17.508	16.328	<sup>1</sup>	17.502	26.855	25.073
Oct .....	13.354	12.700	12.553	12.180	17.314	16.337	<sup>1</sup>	17.686	27.193	23.500
Nov .....	14.130	13.125	12.742	12.616	17.326	15.182	11.739	18.637	30.625	23.500
Dec. ....	14.111	13.298	12.581	13.552	17.376	14.224	12.801	20.133	31.890	23.500
Year's average.....	13.208	12.982	12.738	12.376	16.341	15.269	13.602	17.275	27.202	27.180

	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
Jan....	23 500	(a)	18 918	12 597	13 465	14 510	12 401	14 709	13 822	12 990
Feb....	23 500	16 763	18 569	12 556	12.864	15 355	12.708	14 463	13 999	12 682
March...	23 500	14 856	18 331	11 976	12 567	16 832	13 515	14 004	13 859	13 079
April. ....	25 500	15 240	18 660	12 438	12 573	16.663	13 206	13.252	13 706	12 808
May....	23 500	15 864	18 484	12 742	13 111	15 440	12.772	13 347	13 599	12 621
June....	23 500	17.610	18 065	12 697	13.575	14 663	12 327	13 399	13 656	12 370
July.....	25 904	21 604	18 576	12 170	13 654	14 321	12 390	13 946	13 924	12 532
Aug .....	26.000	22 319	18 346	11 634	13.723	13 822	13.221	14 490	14.174	12 971
Sept .....	26 000	21.755	18 144	11 948	13 748	13.323	12 917	14 376	14 062	12 940
Oct.....	26 000	21 534	15 934	12 673	13.632	12.574	12.933	14 300	13.862	12 958
Nov .....	26 300	19.758	14 257	13 035	13 598	12 727	13.635	14 353	13.576	13 319
Dec. ....	(p)	18 295	13.188	13 555	14.074	12 823	14 260	13 866	13 302	13.774
Year's average.....	24.628	18.691	17 456	12.502	13 582	14.421	13.024	14.042	13.795	12.920

(a) No market.

These figures from the *Engineering and Mining Journal*.

<sup>1</sup> No quotations.

# PRICE AND PRODUCTION STATISTICS 55

## MONTHLY PRICES OF LEAD AT NEW YORK FOR 20 YEARS (In Cents per Pound)

	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917
Jan.....	3.691	4.175	4.700	4.483	4.435	4.321	4.111	3.729	5.921	7.626
Feb.....	3.725	4.018	4.613	4.440	4.026	4.325	4.048	3.827	6.246	8.636
March.....	3.838	3.986	4.459	4.394	4.073	4.327	3.970	4.053	7.136	9.199
April.....	3.993	4.168	4.376	4.412	4.200	4.381	3.810	4.221	7.630	9.288
May.....	4.253	4.287	4.815	4.373	4.194	4.342	3.900	4.274	7.463	10.207
June.....	4.466	4.350	4.343	4.435	4.392	4.325	3.900	5.932	6.936	11.171
July.....	4.447	4.321	4.404	4.499	4.720	4.353	3.891	5.659	6.352	10.710
Aug.....	4.580	4.363	4.400	4.500	4.569	4.624	3.875	4.656	6.244	10.594
Sept.....	4.515	4.342	4.490	4.485	5.048	4.698	3.828	4.610	6.810	8.680
Oct.....	4.351	4.341	4.400	4.265	5.071	4.402	3.528	4.600	7.000	6.710
Nov.....	4.330	4.370	4.422	4.298	4.615	4.293	3.683	5.155	7.042	6.249
Dec.....	4.213	4.560	4.500	4.450	4.303	4.047	3.800	5.355	7.513	6.375
Year's average....	4.200	4.273	4.446	4.420	4.471	4.370	3.862	4.628	6.858	8.787

These figures from the *Engineering and Mining Journal*.

	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
Jan.....	6.782	5.432	8.561	4.821	4.700	7.633	7.972	10.169	9.255	7.577
Feb.....	6.973	5.057	8.814	4.373	4.700	8.050	8.554	9.428	9.254	7.420
March.....	7.201	5.226	9.145	4.084	4.720	8.252	9.013	8.914	8.380	7.577
April.....	6.772	4.982	8.902	4.356	5.115	8.101	8.263	8.005	7.971	7.126
May.....	6.818	5.018	8.576	4.952	5.420	7.306	7.269	7.985	7.751	6.616
June.....	7.611	5.340	8.323	4.485	5.745	7.146	7.020	8.321	8.033	6.414
July.....	8.033	5.626	8.338	4.410	5.729	6.237	7.117	8.151	8.499	6.344
Aug.....	8.050	5.798	8.687	4.382	5.824	6.582	7.827	9.192	8.908	6.681
Sept.....	8.050	6.108	8.177	4.600	6.110	6.856	8.000	9.508	8.786	6.297
Oct.....	8.050	6.487	7.070	4.690	6.530	6.831	8.235	9.513	8.402	6.250
Nov.....	8.050	6.808	6.159	4.683	7.047	6.846	8.689	9.739	8.005	6.259
Dec.....	6.564	7.231	4.727	4.700	7.163	7.469	9.207	9.310	7.855	6.504
Year's average....	7.413	5.759	7.957	4.545	5.734	7.267	8.097	9.020	8.417	6.755

## UNITED STATES PRODUCTION OF MINERAL AND CHEMICAL SUBSTANCES<sup>1</sup>

	1925	1926	1927	1928
Arsenious oxide, short tons.....	11,000	6,000	10,000	9,000
Bauxite, short tons.....	355,000	439,000	359,000	420,000
Cement, short tons.....	29,901,000	30,873,000	32,539,000	33,370,000
Anthracite.....	61,817,000	84,437,000	80,652,000	76,734,000
Coal, bituminous.....	520,053,000	573,367,000	519,804,000	492,755,000
Iron ores.....	71,596,000	77,608,000	68,580,000	70,833,000

<sup>1</sup> Year Book of the American Bureau of Metal Statistics.

# 56 METALLURGISTS AND CHEMISTS' HANDBOOK

## MONTHLY PRICES OF SILVER AT NEW YORK FOR 20 YEARS (In Cents per Fine Troy Ounce)

	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917
Jan.....	55.678	51.750	52.375	53.795	56.260	62.938	57.572	48.855	56.775	75.630
Feb.....	56.000	51.472	51.534	52.222	59.043	61.642	57.506	48.477	56.755	77.585
March....	55.365	50.468	51.454	52.745	58.375	57.870	58.067	50.241	57.935	73.861
April.....	54.505	51.428	53.321	53.325	59.207	59.490	58.519	50.250	64.415	73.875
May.....	52.795	52.905	53.870	53.308	60.880	60.361	58.175	49.915	74.269	74.745
June.....	53.663	52.538	53.462	53.043	61.290	58.990	56.471	49.034	65.024	76.971
July.....	53.115	51.043	54.150	52.630	60.654	58.721	54.678	47.519	62.940	79.010
Aug.....	51.683	51.125	52.912	52.171	61.606	52.293	54.344	47.163	66.083	85.407
Sept.....	51.720	51.440	53.295	52.440	63.078	60.640	53.290	48.680	68.515	100.740
Oct.....	51.431	50.923	55.490	53.340	63.471	60.793	50.654	49.385	67.855	87.332
Nov.....	49.647	50.703	55.635	55.719	62.792	58.995	49.082	51.714	71.604	85.891
Dec.....	48.769	52.226	54.428	54.905	63.365	57.760	49.375	54.971	75.765	85.960
Year's average.	52.864	51.502	53.486	53.304	60.835	59.701	54.811	49.684	65.661	81.417

	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
Jan.....	88.702	101.125	132.827	65.950	65.450	65.668	63.447	68.447	67.705	55.795
Feb.....	85.716	101.125	131.295	59.233	65.290	64.313	64.359	68.472	66.773	57.898
March.....	88.082	101.125	125.551	56.023	64.440	67.556	63.957	67.808	65.880	55.306
April.....	95.346	101.125	119.779	59.337	66.575	66.855	64.139	66.899	64.409	56.399
May.....	99.505	107.135	102.585	59.810	71.154	67.043	65.524	67.580	65.075	56.280
June.....	99.500	110.430	90.957	58.510	71.149	64.861	66.690	69.106	65.481	56.769
July.....	90.625	106.394	91.971	60.260	70.245	63.015	67.159	69.442	64.793	56.360
Aug.....	100.292	111.370	96.168	61.597	69.417	62.793	68.519	70.240	62.380	54.718
Sept.....	101.125	114.540	93.675	66.160	69.515	64.203	69.350	71.570	60.580	55.445
Oct.....	101.125	119.192	83.480	70.970	68.015	63.649	70.827	71.106	54.505	50.035
Nov.....	101.125	127.924	77.734	68.234	65.177	63.818	67.299	69.223	54.141	57.474
Dec.....	101.125	131.976	64.774	65.760	63.905	64.705	68.096	68.889	53.446	57.957
Year's average	96.723	111.122	100.900	62.654	67.528	64.873	66.781	69.065	62.107	56.370

NOTE.—Silver in New York is sold by the fine ounce, 999, in London by the standard ounce, 925 fine.

# PRICE AND PRODUCTION STATISTICS 57

## MONTHLY PRICES OF SPELTER AT ST. LOUIS FOR 20 YEARS (In Cents per Pound)

	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917
Jan.....	4.363	4.991	5.951	5.302	6.292	6.854	5.112	6.211	16.745	9.449
Feb.....	4.638	4.739	5.419	5.368	6.349	6.089	5.228	8.255	18.260	9.875
Mar.....	4.527	4.607	5.487	5.413	6.476	5.926	5.100	8.366	16.676	10.130
Apr.....	4.495	4.815	5.289	5.249	6.483	5.491	4.963	9.837	16.525	9.289
May.....	4.458	4.974	5.041	5.198	6.529	5.256	4.924	14.610	14.106	9.192
June.....	4.393	5.252	4.978	5.370	6.727	4.974	4.850	21.038	11.582	9.201
July.....	4.338	5.252	5.002	5.545	6.966	5.128	4.770	18.856	8.755	8.473
Aug.....	4.556	5.579	5.129	5.803	6.878	5.508	5.418	12.611	8.560	8.190
Sept.....	4.619	5.046	5.364	5.719	7.313	5.444	5.230	13.270	8.820	7.966
Oct.....	4.651	6.043	5.478	5.951	7.276	5.188	4.750	12.596	9.659	7.813
Nov.....	4.909	6.231	5.826	6.223	7.221	5.083	4.962	15.792	11.422	7.672
Dec.....	4.987	6.099	5.474	6.151	7.081	5.004	5.430	15.211	10.495	7.510
Year's average.....	4.578	5.352	5.370	5.608	6.799	5.504	5.061	13.054	12.634	8.730

	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
Jan.....	7.661	6.922	9.133	5.413	4.691	6.815	6.426	7.738	8.304	6.661
Feb.....	7.639	6.273	8.708	4.928	4.485	7.152	6.756	7.480	7.759	6.673
March.....	7.286	6.150	8.531	4.737	4.658	7.706	6.488	7.319	7.332	6.692
April.....	6.715	6.114	8.184	4.747	4.906	7.197	6.121	6.985	7.001	6.338
May.....	7.114	6.079	7.588	4.848	5.110	6.625	5.793	6.951	6.821	6.075
June.....	7.791	6.551	7.465	4.421	5.346	6.031	5.792	6.990	7.112	6.213
July.....	8.338	7.523	7.720	4.239	5.694	6.089	5.898	7.206	7.411	6.229
Aug.....	8.635	7.160	7.835	4.186	6.212	6.325	6.175	7.576	7.376	6.342
Sept.....	9.092	7.473	7.661	4.235	6.548	6.438	6.181	7.753	7.413	6.213
Oct.....	8.451	7.827	7.150	4.605	6.840	6.293	6.324	8.282	7.296	5.996
Nov.....	8.141	8.350	6.247	4.665	7.104	6.347	6.796	8.614	7.199	5.745
Dec.....	7.813	8.350	5.824	4.837	6.990	6.260	7.374	8.565	7.018	5.722
Year's average.....	7.890	6.988	7.671	4.655	5.716	6.607	6.344	7.692	7.337	6.242

# 58 METALLURGISTS AND CHEMISTS' HANDBOOK

## MONTHLY PRICES OF TIN AT NEW YORK FOR 20 YEARS (In Cents per Pound)

	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917
Jan. ....	27.380	28.060	32.700	41.255	42.529	50.298	37.779	34.260	41.825	44.175
Feb. ....	28.978	28.290	32.020	41.614	42.962	48.766	39.830	37.415	42.717	51.420
Mar. ....	30.577	28.727	32.403	40.157	42.577	46.832	38.038	48.426	50.741	54.388
Apr. ....	31.702	29.445	32.976	42.185	43.923	49.115	36.154	47.884	51.230	55.910
May. ....	30.015	29.225	33.125	43.115	46.053	49.038	33.360	38.790	49.125	63.173
June. ....	28.024	29.322	32.769	44.605	45.815	44.820	30.577	40.288	42.231	62.053
July. ....	29.207	29.125	32.695	42.406	44.519	40.260	31.707	37.423	38.510	62.570
Aug. ....	29.942	29.966	33.972	43.319	45.857	41.582	(a)	34.389	38.565	62.681
Sept. ....	28.815	30.293	34.982	39.755	49.135	42.410	32.675	33.125	38.830	61.542
Oct. ....	29.444	30.475	36.190	41.185	50.077	40.462	30.284	33.080	41.241	61.581
Nov. ....	30.348	30.869	36.547	43.125	49.891	39.810	33.304	39.224	44.109	74.740
Dec. ....	29.144	32.913	38.190	44.655	49.815	37.635	33.601	38.779	42.635	87.120
Year's average. ....	29.465	29.725	34.123	42.281	46.096	44.252	34.300	38.590	43.480	61.802

These figures from the *Engineering and Mining Journal*.

(a) No quotations.

	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
Jan. ....	85.500	67.702	61.506	36.000	31.480	37.986	48.750	57.692	62.275	66.415
Feb. ....	92.000	66.801	59.932	32.142	29.835	40.693	53.272	56.517	63.705	69.142
March. ....	(a)	67.934	61.926	28.806	28.426	46.569	54.870	53.038	64.505	69.199
April. ....	(a)	72.500	62.115	30.404	29.810	44.280	49.957	51.380	63.389	67.933
May. ....	(a)	72.500	55.100	32.500	30.149	42.346	44.111	53.675	62.305	67.510
June. ....	(a)	71.240	48.327	29.423	30.707	40.375	42.765	54.885	60.611	67.466
July. ....	(a)	68.090	49.154	27.655	31.025	37.970	46.250	56.683	63.091	64.110
Aug. ....	(p)	57.226	47.620	26.301	32.134	38.841	51.909	56.649	63.260	64.431
Sept. ....	(a)	54.482	44.405	26.680	32.075	41.047	49.095	56.405	68.895	61.490
Oct. ....	(a)	54.377	40.555	27.655	33.935	41.322	50.538	60.462	70.245	58.450
Nov. ....	(a)	53.307	36.854	28.935	35.911	43.495	54.348	62.136	70.630	57.641
Dec. ....	(a)	53.870	34.058	32.486	36.480	46.662	56.245	61.952	68.514	58.452
Year's average. ....	(a)	63.328	50.134	29.916	31.831	41.799	50.176	56.790	65.285	64.353

(a) No average computed.



### WORLD'S PRODUCTION OF ALUMINUM<sup>1</sup> (In Metric Tons)

	1924	1925	1926	1927	1928
United States. . . . .	68,300	68,200	70,000	73,000	80,000
Canada . . . . .	12,500	12,500	12,000	23,000	40,000
France . . . . .	16,300	18,400	23,600	19,840	23,000
Switzerland . . . . .	20,000	22,000	22,000	21,000	20,000
Germany . . . . .	18,700	26,200	29,600	27,400	30,000
Austria-Hungary . . . . .	2,200	3,000	3,000	2,500	2,500
England . . . . .	7,000	9,700	7,300	7,900	7,000
Norway . . . . .	20,000	21,300	24,400	20,847	19,000
Italy . . . . .	2,100	1,900	1,900	2,544	3,500
	167,100	183,200	193,800	197,831	224,850

<sup>1</sup> Year Book of the American Bureau of Metal Statistics. The figures for the United States are largely conjectural.

### MONTHLY AVERAGE PRICES OF ALUMINUM IN NEW YORK (In Cents per Pound)

	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928
Jan. . . . .	33.10	32.00	22.86	17.74	22.75	27.61	27.00	27.00	26.37	23.90
Feb. . . . .	32.26	31.83	24.50	17.33	23.25	27.71	27.00	27.00	25.83	23.90
March. . . . .	29.81	31.50	23.44	17.52	24.95	27.57	27.00	27.00	25.55	23.90
April. . . . .	30.67	31.61	23.25	18.07	26.00	27.46	27.00	27.00	25.55	23.90
May. . . . .	32.21	31.95	23.06	17.92	26.24	26.43	27.00	27.00	25.55	23.90
June . . . . .	32.83	32.00	22.75	17.87	26.25	26.37	27.00	27.00	25.55	23.90
July. . . . .	32.57	32.00	22.65	17.87	26.25	26.37	27.00	27.00	25.55	23.90
Aug. . . . .	32.23	32.21	20.22	17.87	26.07	26.52	27.00	27.00	25.55	23.90
Sept. . . . .	32.50	31.44	19.02	18.26	25.50	27.24	27.00	27.00	25.55	23.90
Oct. . . . .	32.50	29.12	17.85	20.32	25.50	27.16	27.24	27.00	25.29	23.90
Nov. . . . .	32.50	27.80	17.50	20.87	25.80	27.00	28.00	27.00	24.30	23.90
Dec. . . . .	32.48	23.83	17.50	22.52	26.31	27.00	28.00	26.85	24.26	23.90
Year's average. . . . .	32.14	32.72	21.11	18.68	25.41	27.03	27.19	26.99	25.40	23.90

### WORLD'S PRODUCTION OF CADMIUM IN POUNDS (In Pounds)

	United States	Tasmania	Polish Silesia
1922	131,590	80,640	54,448
1923	183,816	275,518	54,434
1924	129,328	356,345	22,615
1925	502,824	400,557	7,837
1926	810,428	358,912	11,574
1927	1,074,654	346,773	13,523
1928	1,875,896 <sup>1</sup>	383,040	9,238

<sup>1</sup> Canada also produced 492,000 lb.

Electricity: Ampere, the unit of current strength,  $I$ ; volt, the unit of electromotive force,  $E$ ; ohm, the unit of resistance,  $R$ ; coulomb, the unit of quantity,  $Q$ ; watt, the unit of power,  $P$ ; joule, the unit of work,  $J$ ; farad, the unit of capacity,  $C$ ;

henry, the unit of inductance,  $L$ .  $t$  = seconds.  $I = \frac{E}{R}$  (Ohm's

law);  $Q = It$ ,  $C = \frac{Q}{E}$ .  $W = QE$ ,  $P = IE$ ,  $P = \frac{E^2}{R} = I^2 R =$

$$\frac{W}{t} = \frac{QE}{t}$$

Heating effect of a current,  $J = I^2 R t = \frac{E^2 t}{R}$ .

### DEFINITIONS OF PHYSICAL TERMS<sup>1</sup>

**Absorption Index.**—When monochromatic light traverses a distance equal to its own wave length,  $\lambda$ , in a material, is the ratio of the amplitude of the emergent light  $J\lambda'$  to that of the entering light  $J\lambda$ .

$$\frac{J\lambda'}{J\lambda} = e^{-2\pi\kappa}$$

when  $\kappa$  is the absorption index.

(A variety of usage prevails regarding the definition of this term. This definition is used in the Smithsonian physical tables.)

**Density.**—The density of a substance is the mass per unit volume. It is usually expressed in terms of grams per cubic centimeter.

**Electrical Conductivity and Resistivity** ( $\chi$ ,  $\rho$ ).—There are two methods of expressing electrical resistivity in common use, each being defined quantitatively in terms of the resistance of a unit specimen. The volume resistivity is  $\rho$  in the equation

$$R = \frac{\rho l}{s}$$

in which  $R$  = resistance,  $l$  = length, and  $s$  = cross-section. The volume resistivity thus defined may be expressed in various units, such as microhm-centimeter (microhm per centimeter cube), ohms per foot of a uniform wire 1 mil in diameter, etc. The commonly used units, in abbreviated terminology, are: microhm-centimeter, microhm-inch, ohm (meter, mm.), ohm (meter, sq. mm.), ohm (mil, foot).

The other kind of resistivity is mass resistivity, and is defined as  $\delta$  in the equation

$$R = \frac{\delta l^2}{m}$$

in which  $m$  = mass of the wire. The usual units of mass resistivity are: ohm (meter, gram), and ohm (mile, pound).

<sup>1</sup> Mainly from Bureau of Standards Circular 100.

**Per Cent. Conductivity.**—The term “conductivity” means the reciprocal of resistivity, but it is used very little in wire calculations. In connection with copper, however, extensive use is made of the per cent. conductivity, which is calculated in practice by dividing the resistivity of the international annealed copper standard at 20°C. by the resistivity of the sample at 20°C.

**Temperature Coefficient of Resistance.**—The temperature coefficient of electrical resistance is the fractional change of resistance per degree change of temperature. Its value varies with the temperature, and hence the temperature from which the resistance change is measured must always be stated or understood. For a temperature  $t_1$ , the temperature coefficient  $\alpha_1$  is defined, for a metal like copper, by

$$R_t = R_{t_1}[1 + \alpha_1(t - t_1)],$$

in which  $R_{t_1}$  = resistance at the temperature  $t_1$  and  $R_t$  = resistance at any other temperature  $t$ . The temperature coefficient that is usually used at 20°, for example, is

$$\alpha_{20} = \frac{R_t - R_{20}}{R_{20}(t - 20)}$$

**Boiling Point.**—The boiling point of a liquid is the temperature at which it boils under atmospheric pressure, or, better, the temperature at which its vapor pressure is equal to the external pressure.

**Brinell Test.**—An indentation is made, by pressure, on a polished surface of the material, using a hardened steel ball. There are several ways of expressing the hardness:

The commonest definition of the BRINELL hardness is the pressure in kilograms per unit area (square millimeters) of the spherical indentation. (Hardness numeral =  $H. N.$ )

$$H. N. = \frac{\text{Pressure}}{\text{area of spherical indentation}} = \frac{P}{\pi D t}$$

$$\text{where } t = \frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}}$$

$P$  = pressure used;

$t$  = depth of indentation;

$D$  = diameter of sphere;

$d$  = diameter of indentation.

Usually 3000 and 500 kg. pressures with a 10 mm. ball, or a 6.4 kg. pressure with a 1.59 mm. ball ( $\frac{1}{16}$  in.) are used.

**Electrolytic Solution Potential ( $E$ ).**—At the junction of a metal and any conducting liquid there is developed a solution potential, which is a measure of the free-energy change of the chemical reaction which is possible at the surface of the metal and liquid. In particular if the chemical reaction consists in the solution of the metal, forming ions, the e.m.f. is

$$E = \frac{RT}{nF} \log \frac{P}{p}$$

where  $R$  = the gas constant;  
 $T$  = absolute temperature;  
 $n$  = valence of metal;  
 $F$  = 96,500 coulombs, the Faraday constant;  
 $P$  = solution pressure of metal;  
 $p$  = osmotic pressure of metal ion formed in solution.

In any electrolytic cell the sum or difference of two such potentials is measured, one of which may be a standard electrode; for example, the hydrogen or the calomel electrode. The e.m.f. of an electrolytic cell of the following type: Normal hydrogen electrode—solution—metal is often called the single e.m.f. ( $e_h$ ) for the metal in the solution; that is, arbitrarily assuming the e.m.f. of the normal hydrogen electrode to be zero.

**Emissivity ( $E$  or  $E_\lambda$ ).**—The coefficient of emissivity  $E$  for any material represents the ratio  $\frac{J_\lambda'}{J_\lambda}$  of the intensity,  $J_\lambda'$ , of radiation of some particular wave length or color,  $\lambda$ , emitted by the material at an absolute temperature  $T$  to that  $J$ , emitted by a black-body radiator at the same temperature.

The coefficient of total emissivity  $E$  for any material represents that ratio  $\frac{J_1}{J}$  of the intensity of radiation of all wave lengths,  $J_1$ , emitted by the material at an absolute temperature,  $T$ , to that,  $J$ , emitted by a black body radiator at the same temperature.

This coefficient is always less than 1, and for metals is equal to 1 minus the reflection coefficient for normal incidence (KIRCHHOFF'S law.)

For any optical pyrometer using monochromatic light a value of the observed or "black-body" temperature of any substance (not inclosed) is reduced to the true temperature by the following formula:

$$\frac{1}{T} - \frac{1}{T_0} = \frac{\lambda \log E_\lambda}{6232}$$

where  $T$  = true absolute temperature;  
 $T_0$  = observed absolute temperature;  
 $\lambda$  = wave length in microhm (0.001 mm.);  
 $E_\lambda$  = relative emissivity of substance for wave length.

**Erichsen Test.**—This test is carried out to determine the ductility of sheets. An indentation is made in the sheet with a die with hemispherical end. The greatest depth of indentation which can be made without incipient cracking of the sheet, measured in inches or millimeters, is known as the ERICHSEN value for the sheet.

**Heat of Fusion.**—The heat of fusion of a substance is the quantity of heat absorbed in the transformation of unit mass (1 g.) of the solid substance to the liquid state at the same temperature.

**Magnetic Properties.**—The usual magnetic characteristics of a substance are given either by the permeability,  $\mu$ , or the susceptibility,  $\kappa$ . Permeability is the ratio of the magnetic induction ( $B$  in gaussess per square centimeter) to the magnetizing force ( $H$  in gaussess per square centimeter). This is indicated by the relation

$$\kappa = \frac{B}{H}$$

Susceptibility is given, in corresponding units, by

$$\kappa = \frac{\mu - 1}{4\pi}$$

For all materials except iron and a few other ferro-magnetic metals  $\mu$  is very nearly unity and  $\kappa$  is only a few millionths. When  $\kappa$  is positive in sign the substance is paramagnetic, when negative diamagnetic. The susceptibility as thus defined is sometimes called volume susceptibility and indicated by  $\kappa_v$ . A quantity called mass susceptibility is also used, and is equal to the volume susceptibility divided by the density of the material; it is represented by  $\kappa_m$ .

**Melting Point.**—The melting or fusing point of a substance is the temperature at which it fuses (under atmospheric pressure), or more accurately the temperature at which the solid and the liquid metal are in equilibrium with each other.

**Peltier Effect** ( $\pi$ ).—When at the junction of two metals current flows from one to the other, heat is in general absorbed or liberated (see "Thermoelectromotive Force" below); the coefficient, the amount of heat liberated when a unit quantity of electricity flows across the junction, is known as  $\pi$  (measured either in calories per coulomb or in volts), the Peltier effect.

**Impact-tests.** *Charpy's Test.*—The test piece lies at the bottom of the course of a pendulum, and the energy retained by the pendulum after breaking the specimen is shown by the height to which it swings up. The difference between this figure and the total energy of the pendulum is the energy absorbed.

*Frément.*—The test piece is broken by a knife edge which falls 4 m. and has a mass of 10 kg. The residual energy is measured.

*Guillery.*—The specimen is broken by a knife-edge carried by a flywheel and the energy absorbed is measured by the lessening of the velocity of the flywheel.

*Izod.*—While in the Charpy method the test piece is supported by both ends, the Izod supports it at only one.

*Marten's Sclerometer.*—This machine uses a 90° conical diamond point at one end of a weighted lever arm, under which the specimen moves on a traversing table. The hardness number was the load, in grams, necessary to produce a cut having an average width of 10 $\mu$ , and the term "scoring hardness" was used to designate hardness determined in this way.

**Scratch Hardness.** *Biefbaum's Test.*—C. H. BIERBAUM developed an instrument known as the "microcharacter," in

which a jewel, ground to a point, is loaded and dragged across the surface to be tested for hardness, the resulting track being examined under a microscope. The loading in the jewel is 3 gr. BIERBAUM defines "microhardness,"  $\kappa$  in terms of the width of the cuts, in microns.

$$\kappa = \mu^{-2}10^4.$$

Hardnesses as found by him were as follows:

Lead, c.p., Picher .....	7.03
Tin, c.p., electro.....	11.7
Copper, electrolytic.....	78.4
Antimony, commercial... ..	121.0
SnSb crystals in babbitt.....	208.0
Nickel, c.p., International Nickel Co. ....	244.0
PCu <sub>3</sub> crystals in phosphor bronze .....	267.0
Iron, Swedish, softest crystals.....	420.0
Cobalt, c.p., International Nickel Co. ....	625.0
SnCu <sub>3</sub> in copper-tin bronze.....	750.0
SnCu <sub>4</sub> , hardest crystal in high-Cu hardened babbitt ..	1006.0
Hardened steel, Johansson test blocks .....	2229.0
SnO <sub>2</sub> (fused) as found in burned bronze.....	5390.0
BIERBAUM'S paper appeared in <i>Trans. A.I.M.E.</i> , 1923, Vol. 69, p. 972.	

**Ductility.**—Ability to withstand stretch without rupture. Ductility is usually measured by the percentage of elongation after rupture over a gage length laid off on a specimen before stretching, or by the reduction of area of the original cross-section of a specimen when tested in tension.

**Elastic Limit.**—The term is, unfortunately, used very loosely in general practice. In this report the term elastic limit or set elastic limit is used to denote the highest unit stress at which material will completely recover its form after the stress is removed. *Proportional limit*, or proportional elastic limit, is used to denote the highest unit stress at which stress is proportional to deformation. The values found for both elastic limit and proportional limit are dependent on the accuracy of apparatus used and the precision of plotting stress-strain diagrams. For practical purposes elastic limit and proportional limit may be regarded as interchangeable terms. The yield point is that unit stress at which material shows a sudden marked increase in the rate of deformation without increase in load. It is usually determined by the sudden drop in the balance-beam of the testing machine as strain is applied to the specimen at a uniform rate, or by a sudden increase of deformation which can be seen by the use of a pair of dividers on the specimen.

**Hysteresis, Mechanical.**—If load is applied to a specimen, and is removed, then, if the specimen is perfectly elastic under the stress caused by the load, the energy expended in loading the specimen is all given back when the load is removed. If the specimen is not perfectly elastic under the stress caused by the applied load, then some of the energy applied is dis-

sipated as heat. This dissipated energy is called mechanical hysteresis, and is measured by the area of the loop between the stress-strain diagram for application of load and the stress-strain diagram for release of load.

**Refractive Index.**—The ratio of the velocity of light in vacuum to that in any material is called the refractive index ( $\eta$ ) of that material. (This physical quantity ceases to have a meaning at or near an absorption band in the material.)

**Scleroscope Test (Shore).**—A hardened hammer falls from a constant height onto a polished surface of the material, and the distance of rebound is measured on a scale 10 in. long, divided into 140 equal parts. The scleroscope hardness is expressed as the distance of rebound on this arbitrary scale, the value of 100 representing the hardness on this scale of hardened steel.

**Specific Heat.**—( $\sigma$ ).—The true specific heat of a substance is  $\frac{du}{dt}$  when  $u$  is the total internal heat or energy of unit mass

of the substance. The mean specific heat is defined as  $\frac{q}{t_1 - t_2}$  per unit mass when  $q$  is the quantity of heat absorbed during a temperature change from  $t_2$  to  $t_1$ . It is generally considered as the quantity of heat (calories) required to raise the temperature of unit mass (grams) by unity (degrees Centigrade), either at constant volume or at constant pressure. Unless otherwise noted the specific heat of solids refers to that at constant (atmospheric) pressure. The true specific heat (constant pressure) of metals may usually be expressed sufficiently by an equation of the type

$$\sigma = A + Bt + Ct^2 + \dots$$

**Tensile Test.**—The quantities determined in the tension test are the following:

The *ultimate tensile strength* is the maximum load per unit area of original cross-section borne by the material.

The *yield point* is the load per unit of original cross-section at which a marked increase in the deformation of the specimen occurs without increase of load.

The *elastic limit* is the greatest load per unit of original cross-section which does not produce a permanent set.

The *proportional limit* is the load per unit of original cross-section at which the deformations cease to be directly proportional to the loads.

The *percentage elongation* is the ratio of the increase of length at rupture between arbitrary points on the specimens to this original length.

The *percentage reduction of area* is the ratio of the decrease of cross-section at the "neck" or most reduced section at rupture to the original section.

**Thermal Conductivity ( $\lambda$ ).**—The coefficient of thermal conductivity ( $\lambda$ ) expresses the quantity of heat (small calories) which flows in unit time (seconds) across a unit cube (centi-

meter) of the material whose opposite faces differ in temperature by unity ( $1^{\circ}\text{C}.$ ). Its *temperature coefficient* is expressed as

$$\alpha_{t_0} = \frac{\lambda_t - \lambda_{t_0}}{\lambda_{t_0}(t - t_0)}.$$

**Thermal Expansion.**—If  $l_t$  is any linear dimension of a solid at any temperature  $\frac{dl}{l dt}$  is the linear coefficient of thermal expansivity of that solid in the direction of  $l$ . It is not in general proportional to the temperature except approximately over small temperature intervals, but may be expressed in the following manner:

$$\frac{dl}{l dt} = a + bt + ct^2 \dots$$

For small temperature intervals a mean coefficient ( $\alpha$ ) is often determined; that is,

$$\alpha_{t_0} = \frac{l_t - l_{t_0}}{l_{t_0}(t - t_0)}$$

**Thermoelectromotive Force ( $E$ ).**—In an electric circuit composed of two dissimilar conductors, the two junctions being at different temperatures, there exists in general an electromotive force, called the thermoelectromotive force, between the two metals, the value of which is a function both of the temperature and the difference of temperature between the two junctions. It is shown thermodynamically that this e.m.f. is related to the THOMSON and Peltier effects in the following manner:

$$\pi = \left. \begin{array}{l} T \frac{dE}{J dt} \\ J \frac{d^2E}{J dt^2} \end{array} \right\} \begin{array}{l} \text{and is expressed in calories per coulomb} \\ \text{when} \end{array}$$

$$\sigma_1 - \sigma_2 = \left. \begin{array}{l} T \frac{d^2E}{J dt^2} \end{array} \right\} \cdot \quad J = \frac{418 \text{ dynes} \times 10^6}{\text{calories}}$$

when  $E$  is the thermal e.m.f.,  $T$  the absolute temperature,  $\frac{dE}{dt}$  the thermoelectric power (see below), and  $\sigma_1 - \sigma_2$  the difference in the THOMSON effect of two materials. The equation  $\frac{dE}{dt} = A + BT$  fits experimental data over a range of several hundred degrees.

**Thermoelectric Power.**—If  $E$  is the thermoelectromotive force of two metals,  $\frac{dE}{dT}$  is the thermoelectric power; for a given temperature it is approximately the thermal e.m.f. of a couple of which the temperatures of the two junctions differ by  $1^{\circ}\text{C}.$

**Thomson Effect.**—When a current flows in a conductor from a point at one temperature to a point at another, heat is in



general liberated, or absorbed, and an e.m.f. or a counter-e.m.f. is produced. The coefficient of the THOMSON effect is the amount of heat liberated or absorbed when a unit quantity of electricity flows from a point at temperature  $t$  to one at  $t + dt$ , and is equal to  $\sigma dt$  cal. per coulomb where  $\sigma$  is the THOMSON specific heat of electricity. It is positive for any material when heat is generated in that material as a current flows from a region of higher to one of lower temperature.

MISCELLANEOUS CONSTANTS (ATOMIC, MOLECULAR, ETC.<sup>1</sup>)

Elementary electrical charge, charge on electron, $\frac{1}{2}$ charge on a particle.....	$e = 4.774 \times 10^{-10}$ csu (M) $= 1.591 \times 10^{-20}$ emu. $= 1.591 \times 10^{-19}$ coulomb
Mass of an electron.....	$m = 9.01 \times 10^{-28}$ g
Radius of an electron.....	about $2 \times 10^{-13}$ cm.
Ratio $e/m$ , small velocities $e/m$	$= 1.766 \times 10^7$ emu. $g^{-1}$
Number of molecules per gram molecule or per gram molecular weight (Avogadro constant).....	$N = 6.062 \times 10^{23}$ (M)
Number of gas molecules " per cm. <sup>3</sup> , 76 cm., 0°C. (Loschmidt's number)....	$n = 2.705 \times 10^{19}$ (M)
Number of gas molecules per cm. <sup>3</sup> , 0°C. at $1 \times 10^6$ bars.....	$2.670 \times 10^{19}$
Kinetic energy of transla- tion of a molecule at 0°C.	$E_0 = 5.621 \times 10^{-14}$ erg (M)
Constant of molecular en- ergy, $E_0/T$ = change of translational energy per °C.....	$\epsilon = 2.058 \times 10^{-16}$ erg/°C (M) $= 1.662 \times 10^{-24}$ g (M)
Mass of hydrogen atom....	$\bullet$
Radius of hydrogen mole- cule about.....	$\bullet$ $10^{-8}$ cm.
Mean free path, ditto, 76 cm., 0°C. about.....	$\bullet$ $L = 1.6 \times 10^{-5}$ cm./sec.
Sq. rt. mean sq. velocity, ditto, 76 cm., 0°C.....	$G = 1.84 \times 10^6$ cm./sec.
Arithmetical average veloc- ity, ditto, 76 cm., 0°C...	$\Omega = 1.70 \times 10^6$ cm./sec.
Average distance apart of molecules, 76 cm., 0°C...	$= 3 \times 10^{-6}$ cm.
Boltzmann gas constant = constant of entropy equa- tion = $R/N = p_0 V_0 / T N$ $= (\frac{3}{2})\epsilon$ .....	$k = 1.372 \times 10^{-16}$ erg/°C.

<sup>1</sup> Courtesy Smithsonian Institution. These are Tables 528 and 529 of the "Smithsonian Tables."

Volume per mol (e) or gram-molecular weight of ideal gas, 76 cm., 0°C (1.01323 $\times 10^6$ bars).....	= 22.412 liters
Ditto, 1 $\times 10^6$ bars, 0°C. (75 cm. Hg.).....	= 22.708 liters
Gas constant: $PV_m = RT$ , $V_m$ = vol. molec. wt. in grams when $P$ in g./cm. <sup>2</sup> , $V_m$ in cm. <sup>3</sup> .....	$R = 84.780$ g-cm./°C.
when $P$ in atmospheres, $V_m$ in liters .....	$R = 0.08204$ l-atm/°C.
when $P$ in dynes, $V_m$ in cm. <sup>3</sup> .....	$R = 8.315 \times 10^7$ ergs/°C.
Absolute zero = 0° Kelvin 1 Megabar (= Meteorological "bar") = $10^6$ dynes/cm. <sup>2</sup> = 1.013 kg/cm. <sup>2</sup> .....	= - 273.13°C.
Mechanical equivalent of heat, 1 g. (20°C.) cal.	= 0.987 atmosphere = $4.184 \times 10^7$ ergs = 4.184 Joules
Faraday constant...	$F = 96494$ coulombs
Velocity of light in vacuo...	$c = 2.99860 \times 10^{10}$ cm./sec.
Planck's element of action	$h = 6.547 \times 10^{-27}$ erg. sec. (M)
Rydberg's fundamental frequency.....	$V_0 = 3.28880 \times 10^{15}$ sec. <sup>-1</sup>
Rydberg's constant, $V_0/c$ ...	$N = 109678.7$
Wien's constant of spectral radiation .....	$c_2 = 1.4312$ for $\lambda$ in cm. (M)
Stefan-Boltzmann constant of total radiation .....	$\sigma = 5.72 \times 10^{-12}$ watt/cm. <sup>2</sup> (M)
Grating space in calcite .....	$d = 3.030$ Å
Grating space in rock-salt (Uhler, Cooksey) .....	= $2.814 \times 10^{-8}$ cm.
Potential difference in volts for X-rays of wave-length $\lambda$ in cm = $V\lambda = hc/e$	= $1.241 \times 10^{-4}$ volt. cm.
Reference: (M) MILLIKAN, <i>Phil. Mag.</i> 34, 1, 1917.	
1 meter = 1,553,164.13 red cadmium wave lengths.	

RADIATION WAVE-LENGTH LIMITS

Hertzian waves, longest .....	2 000 000.0 cm.
Hertzian waves, shortest .....	0.2 cm.
Infra-red, longest, reststrahlung, focal-isolation .....	0.03 cm.
Infra-red, spectroscopically studied .....	0.002 cm.
Visible, longest .....	0.000 08 cm.
Visible, shortest .....	0.000 04 cm.
Ultra-violet, Lyman, shortest* .....	0.000 006 cm.
X-rays, longest .....	0.000 000 12 cm.
X-rays, shortest .....	0.000 000 001 cm.
$\gamma$ rays, longest .....	0.000 000 013 cm.
$\gamma$ rays shortest .....	0.000 000 000 7 cm.

\* 0.000 0020 cm. (MILLIKAN-SAWYER, 1920)

COMPOSITION OF THE AIR<sup>1</sup>

	By weight	By volume	Expired air by volume
Oxygen .....	23.024	20.941	15.4
Nitrogen .....	75.539	78.122	79.2
Argon <sup>2</sup> .....	1.337	0.937	
CO <sub>2</sub> .....	0.040	.....	4.33

<sup>1</sup>According to RAMSAY (cf. BENSON'S "Industrial Chemistry," p 38 The Macmillan Co.).

<sup>2</sup> Including the other inert gases. The rare gases are present in air in the following proportions by weight: krypton, 0.028 per cent.; xenon, 0.005; neon, 0.00038; helium, 0.000056 per cent.

PSYCHROMETRIC TABLES<sup>1</sup>

**Measurement of Atmospheric Moisture.**—The quantity of moisture mixed with the air under different conditions of temperature and degree of saturation may be measured in several distinctly different ways. Many of these, however, are not practicable methods for daily observations, or are not sufficiently accurate. Probably the most convenient of all methods and the one most generally employed is to observe the temperature of evaporation—that is, the difference between the temperatures indicated by wet- and dry-bulb thermometers. The most reliable instrument for this purpose is the sling, or whirled psychrometer. In special cases, rotary fans or other means may be employed to move the air rapidly over the thermometer bulbs. In any case satisfactory results cannot be obtained from observations in relatively stagnant air. A strong ventilation is absolutely necessary to accuracy.

**Sling Psychrometer.**—This instrument consists of a pair of thermometers, provided with a handle, which permits the thermometers to be whirled rapidly, the bulbs being thereby strongly affected by the temperature of and moisture in the air. The bulb of the lower of the two thermometers is covered with thin muslin, which is wet at the time an observation is made.

<sup>1</sup> C. F. MARVIN'S Tables, Weather Bureau Bulletin No. 235.

*Continued on page 89.*

**TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT**  
**Pressure = 30.0 inches of mercury**

Air temp., °F.		Vapor press., in. Hg.	Depression of wet-bulb thermometer ( $t-t'$ )																
			0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0		
40	0.0039	52																	
39		41	50																
38		44	49																
37		46	48																
36		48	46																
35	0.0051	45																	
34		54	43	59															
33		57	42	56															
32		61	40	53															
31		65	38	50															
30	0.0069	36	47																
29		74	35	45															
28		78	33	42	58														
27		83	32	40	54														
26		89	30	38	50														
25	0.0094	29	36	46															
24	0.0100	28	34	43	60														
23		106	27	32	40	54													
22		112	26	31	38	49									59				
21		119	25	29	35	45									56				
20	0.0126	23	28	33	42	57									54				
19		133	22	26	31	39	51								51				
18		141	21	25	29	36	46								49	59			
17	0.0150	20	23	28	33	42	59								47	56			
16		159	19	22	26	31	38	51							46	53			
15	0.0168	18	21	24	29	35	45								44	50	50		
14		178	16	19	23	27	32	40	56						42	47	55		
13		188	15	18	21	25	30	36	48										
12		199	14	17	20	23	27	33	43	59									
11		210	13	16	18	22	25	30	38										
10	0.0222	12	14	17	20	24	28	33	44										
9		234	11	13	16	18	22	26	30	38	51								
8		247	10	12	14	17	20	24	28	34	44								
7		260	9	11	13	16	18	22	26	31	38	51							
6		275	8	10	12	14	17	20	23	28	33	44							
5	0.0291	7	8	10	13	15	18	21	25	30	37	50							
4		307	6	7	9	11	14	16	19	22	27	32	42	59					
3		325	4	6	8	10	12	14	17	20	24	29	35	47					
2		344	3	5	7	8	10	13	15	18	21	25	30	38	53				
1		363	2	4	5	7	9	11	13	16	19	22	27	32	42	60			
0	0.0383	1	3	4	6	7	9	12	14	17	20	23	28	35	48				
+		403	± 0	2	3	4	6	8	10	12	15	17	20	25	30	37	50		
2		423	± 1	1	2	3	5	6	8	10	13	15	18	21	26	31	40		
3		444	2	1	1	2	4	5	7	9	11	13	16	19	22	27	32		
4		467	3	2	± 0	1	2	4	5	7	9	11	14	16	19	23	28		
5	0.0491	4	3	± 1	± 0	1	1	3	4	6	7	9	12	14	17	20	24		
6		515	5	4	3	± 1	± 0	1	3	4	6	8	10	12	15	17	21		
7		542	6	5	4	2	± 1	± 0	1	3	4	6	8	10	12	15	18		
8		576	7	6	5	4	3	± 1	± 0	2	3	5	6	8	10	13	15		
9		600	8	7	6	5	4	3	± 1	± 0	2	3	5	6	8	10	13		
10	0.0631	9	8	7	6	5	4	3	± 1	± 0	2	3	5	6	8	10	13		
11		665	10	9	8	7	6	5	4	3	± 1	± 0	1	3	4	6	8		
12		690	11	10	9	8	7	6	5	4	3	± 2	± 0	1	3	4	6		
13		735	12	11	10	9	8	7	6	5	4	3	± 2	± 0	1	2	4		
14		772	13	12	11	10	9	8	7	6	5	4	3	± 2	± 1	1	2		
15	0.0810	14	13	12	11	10	9	8	7	6	5	4	3	± 2	± 1	1	0		
16		850	15	14	13	12	11	10	9	8	7	6	5	4	± 3	± 1	0		
17		891	15	15	14	13	12	11	10	9	8	7	6	5	4	± 3	± 1		
18		933	17	17	16	15	14	13	12	11	10	9	8	7	6	5	5		
19	0.0979	18	18	17	16	15	15	14	13	12	11	10	9	8	7	6	6		
20	0.1026	19	19	18	17	16	16	15	14	13	12	12	11	10	9	8	8		

## TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

*Continued*

Pressure = 30.0 inches of mercury

		Depression of wet-bulb thermometer ( $t - t'$ )														
Air temp., $t$		3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0
2		-56														
3		-43														
4		-34	-46													
5		-29	-36	-49												
6		-25	-30	-39	-53											
7		-21	-26	-31	-41	-58										
8		-18	-22	-26	-32	-42										
9		-15	-19	-22	-27	-33	-44									
10		-13	-16	-19	-23	-27	-34	-45								
11		-10	-13	-16	-19	-22	-27	-34	-46							
12		-8	-10	-13	-15	-19	-22	-27	-31	-47						
13		-6	-8	-10	-12	-15	-18	-22	-27	-34	-46					
14		-4	-6	-8	-10	-12	-15	-18	-22	-27	-33	-45				
15		-2	-4	-5	-7	-9	-12	-15	-18	-21	-26	-32	-44			
16	$\pm 0$	-2	-3	-5	-7	-9	-11	-14	-17	-20	-25	-31	-42			
17	$\pm 2$	$\pm 0$	-1	-3	-4	-6	-8	-11	-13	-16	-20	-24	-30	-39	-57	
18	$\pm 3$	$\pm 2$	$\pm 1$	-1	-2	-4	-6	-8	-10	-13	-16	-19	-23	-29	-37	
19	$\pm 5$	$\pm 4$	$\pm 3$	$\pm 1$	$\pm 0$	-2	-4	-5	-7	-10	-12	-15	-18	-22	-27	
20	$\pm 7$	$\pm 6$	$\pm 4$	$\pm 3$	$\pm 2$	$\pm 0$	-1	-3	-5	-7	-9	-11	-14	-17	-21	

**The Wet Bulb.**—It is important that the muslin covering for the wet bulb be kept in good condition. The evaporation of the water from the muslin always leaves in its meshes a small quantity of solid material, which sooner or later somewhat stiffens the muslin so that it does not readily take up water. This will be the case if the muslin does not readily become wet after being dipped in water. Of this account it is desirable to use as pure water as possible, and also to renew the muslin from time to time. New muslin should always be washed to remove sizing, etc., before being used. A small rectangular piece wide enough to go about one and one-third times around the bulb, and long enough to cover the bulb and that part of the stem below the metal back, is cut out, *thoroughly wetted* in clean water, and neatly fitted around the thermometer. It is tied first around the bulb at the top, using a moderately strong thread. A loop of thread to form a knot is next placed around the bottom of the bulb, just where it begins to round off. As this knot is drawn tighter and tighter the thread slips off the rounded end of the bulb and neatly stretches the muslin covering with it, at the same time securing the latter at the bottom..

**To Make an Observation.**—The so-called wet bulb is thoroughly saturated with water by dipping it into a small cup. The thermometers are then whirled rapidly for 15 or 20 seconds; stopped and quickly read, the *wet bulb* first. This reading is kept in mind, the psychrometer immediately whirled again and a second reading taken. This is repeated three or four times,

*Continued on page 109.*

## TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

*Continued*

Pressure = 30.0 inches of mercury

Air temp., °F.	Vapor press., in. Hg.	Depression of wet-bulb thermometer ( $t - t'$ )														
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
20	0.103	18	16	14	12	10	8	5	2	-2	-7	-13	-21	-37		
21	0.108	19	18	16	14	12	9	7	3	0	-4	-9	-16	-27	-60	
22	0.113	20	19	17	15	13	11	8	5	+2	-2	-6	-12	-20	-38	
23	0.118	21	20	18	16	14	12	10	7	4	+0	-4	-9	-16	-26	-57
24	0.124	23	21	19	17	15	13	11	9	6	+2	-1	-6	-12	-20	-35
25	0.130	24	22	20	19	17	15	13	10	8	+5	1	-3	-8	-15	-25
26	0.136	25	23	22	20	18	16	14	12	9	7	3	-1	-5	-11	-18
27	0.143	26	24	23	21	19	18	16	13	11	8	5	+2	-2	-7	-14
28	0.150	27	25	24	22	21	19	17	15	13	10	7	4	+0	-4	-9
29	0.157	28	26	25	23	22	20	18	16	14	12	9	6	+3	-1	-5
30	0.164	29	27	26	25	23	21	20	18	16	14	11	8	5	+2	-2
31	0.172	30	28	27	26	24	23	21	19	17	15	13	10	8	4	+0
32	0.180	31	30	28	27	25	24	22	21	19	17	15	12	10	7	+3
33	0.187	32	31	29	28	27	25	24	22	20	18	16	14	12	9	6
34	0.195	33	32	30	29	28	26	25	23	22	20	18	16	13	11	8
35	0.203	34	33	31	30	29	28	26	25	23	21	19	17	15	13	10
36	0.211	35	34	32	31	30	29	27	26	24	23	21	19	17	15	12
37	0.219	36	35	33	32	31	30	28	27	26	24	22	21	19	17	14
38	0.228	37	36	34	33	32	31	29	28	27	25	24	22	20	18	16
39	0.237	38	37	35	34	33	32	31	29	28	27	25	23	22	20	18
40	0.247	39	38	37	35	34	33	32	30	29	28	26	25	23	21	20
41	0.256	40	39	38	36	35	34	33	31	30	29	27	26	24	23	21
42	0.266	41	40	39	38	36	35	34	33	31	30	29	27	26	24	23
43	0.277	42	41	40	39	37	36	35	34	32	31	30	28	27	25	24
44	0.287	43	42	41	40	38	37	36	35	34	32	31	30	28	27	25
45	0.298	44	43	42	41	40	38	37	36	35	34	32	31	30	28	27
46	0.310	45	44	43	42	41	40	38	37	36	35	34	32	31	30	28
47	0.322	46	45	44	43	42	41	40	38	37	36	35	33	32	31	29
48	0.334	47	46	45	44	43	42	41	40	38	37	36	35	33	32	31
49	0.347	48	47	46	45	44	43	42	41	40	38	37	36	34	33	32
50	0.360	49	48	47	46	45	44	43	42	41	40	38	37	36	34	33
51	0.373	50	49	48	47	46	45	44	43	42	41	40	38	37	36	34
52	0.387	51	50	49	48	47	46	45	44	43	42	41	40	38	37	36
53	0.402	52	51	50	49	48	47	46	45	44	43	42	41	40	38	37
54	0.417	53	52	51	50	49	48	47	46	45	44	43	42	41	40	38
55	0.432	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40
56	0.448	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41
57	0.465	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42
58	0.482	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43
59	0.499	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44
60	0.517	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45
61	0.536	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46
62	0.555	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47
63	0.575	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
64	0.595	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49
65	0.616	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50
66	0.638	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51
67	0.661	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52
68	0.684	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53
69	0.707	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54
70	0.732	69	68	67	66	65	64	63	62	61	60	59	58	57	56	55
71	0.757	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56
72	0.783	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57
73	0.810	72	71	70	69	68	67	66	65	64	63	62	61	60	59	58
74	0.838	73	72	71	70	69	68	67	66	65	64	63	62	61	60	59
75	0.866	74	73	72	71	70	69	68	67	66	65	64	63	62	61	60
76	0.896	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61
77	0.926	76	75	74	73	72	71	70	69	68	67	66	65	64	63	62
78	0.957	77	76	75	74	73	72	71	70	69	68	67	66	65	64	63
79	0.989	78	77	76	75	74	73	72	71	70	69	68	67	66	65	64
80	1.022	79	78	77	76	75	74	73	72	71	70	69	68	67	66	65

# PHYSICAL CONSTANTS

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## TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

*Continued*

Pressure = 30.0 inches of mercury

Air temp., $t$	Vapor press., in. Hg.	Depression of wet-bulb thermometer ( $t - t'$ )														
		8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
25	0.130	—51														
26	0.136	—32														
27	0.143	—23	—45													
28	0.150	—17	—29													
29	0.157	—12	—20	—39												
30	0.164	—7	—14	—25	—57											
31	0.172	—4	—10	—18	—31											
32	0.180	—1	—6	—12	—21	—42										
33	0.187	+2	—2	—7	—14	—26										
34	0.195	+5	+1	—3	—9	—17	—32									
35	0.203	+7	+4	+0	—5	—11	—20	—41								
36	0.211	+10	+7	+3	—1	—6	—14	—25	—58							
37	0.219	+12	+9	+6	+2	—3	—8	—16	—29							
38	0.228	+14	+11	+8	+5	+1	—4	—10	—19	—36						
39	0.237	+16	+13	+11	+8	+4	+0	—5	—12	—22	—47					
40	0.247	+18	+15	+13	+10	+7	+3	—1	—6	—14	—26					
41	0.256	+19	+17	+15	+12	+10	+6	+2	—2	—9	—16	—30				
42	0.266	+21	+19	+17	+14	+12	+9	+6	+2	—3	—9	—18	—36			
43	0.277	+22	+20	+19	+16	+14	+11	+9	+5	+1	—4	—11	—21	—45		
44	0.287	+24	+22	+20	+18	+16	+13	+11	+8	+4	+0	—5	—12	—24	—60	
45	0.298	+25	+23	+22	+20	+18	+15	+13	+10	+7	+4	—1	—6	—14	—27	—30
46	0.310	+27	+25	+23	+21	+20	+17	+15	+13	+10	+7	+3	—2	—7	—16	—17
47	0.322	+28	+26	+25	+23	+21	+19	+17	+15	+12	+9	+6	+2	—3	—9	—17
48	0.334	+29	+28	+26	+25	+23	+21	+19	+17	+14	+12	+9	+5	+1	—4	—10
49	0.347	+30	+29	+28	+26	+24	+23	+21	+19	+16	+14	+11	+8	+5	+0	—5
50	0.360	+32	+30	+29	+27	+26	+24	+22	+21	+18	+16	+13	+11	+8	+4	—0
51	0.373	+33	+32	+30	+29	+27	+26	+24	+22	+20	+18	+16	+13	+10	+7	+3
52	0.387	+34	+33	+32	+30	+29	+27	+26	+24	+22	+20	+18	+16	+13	+10	+7
53	0.402	+36	+34	+33	+32	+30	+29	+27	+26	+24	+22	+20	+18	+15	+13	+10
54	0.417	+37	+36	+34	+33	+32	+30	+29	+27	+25	+24	+22	+20	+18	+15	+12
55	0.432	+38	+37	+36	+34	+33	+32	+30	+29	+27	+25	+24	+22	+20	+17	+15
56	0.448	+40	+39	+37	+36	+34	+33	+32	+30	+29	+27	+25	+24	+22	+19	+17
57	0.465	+41	+40	+39	+37	+36	+34	+33	+32	+30	+29	+27	+25	+24	+21	+19
58	0.482	+42	+41	+40	+39	+37	+36	+35	+33	+32	+30	+29	+27	+25	+23	+21
59	0.499	+44	+43	+41	+40	+39	+37	+36	+35	+33	+32	+30	+29	+27	+25	+23
60	0.517	+45	+44	+43	+41	+40	+39	+38	+36	+35	+33	+32	+30	+29	+27	+25
61	0.536	+46	+45	+44	+43	+42	+40	+39	+38	+36	+35	+33	+32	+30	+29	+27
62	0.555	+47	+46	+45	+44	+43	+42	+40	+39	+38	+36	+35	+33	+32	+30	+29
63	0.575	+49	+48	+47	+45	+44	+43	+42	+41	+39	+38	+36	+35	+34	+32	+30
64	0.595	+50	+49	+48	+47	+46	+44	+43	+42	+41	+39	+38	+37	+35	+34	+32
65	0.616	+51	+50	+49	+48	+47	+46	+45	+43	+42	+41	+40	+38	+37	+35	+34
66	0.638	+52	+51	+50	+49	+48	+47	+46	+45	+44	+42	+41	+40	+38	+37	+35
67	0.661	+53	+53	+52	+50	+49	+48	+47	+46	+45	+44	+43	+41	+40	+38	+37
68	0.684	+55	+54	+53	+52	+51	+50	+49	+48	+46	+45	+44	+43	+42	+40	+39
69	0.707	+56	+55	+54	+53	+52	+51	+50	+49	+48	+46	+45	+44	+43	+42	+40
70	0.732	+57	+56	+55	+54	+53	+52	+51	+50	+49	+48	+46	+45	+44	+43	+42
71	0.757	+58	+57	+56	+55	+54	+53	+52	+51	+50	+49	+48	+47	+46	+45	+43
72	0.783	+59	+58	+58	+57	+56	+55	+54	+53	+52	+51	+50	+48	+47	+46	+45
73	0.810	+60	+60	+59	+58	+57	+56	+55	+54	+53	+52	+51	+50	+49	+48	+46
74	0.838	+62	+61	+60	+59	+58	+57	+56	+55	+54	+53	+52	+51	+50	+49	+48
75	0.866	+63	+62	+61	+60	+59	+58	+57	+56	+55	+54	+53	+52	+51	+50	+49
76	0.896	+64	+63	+62	+61	+60	+60	+59	+58	+57	+56	+55	+54	+53	+52	+51
77	0.926	+65	+64	+63	+62	+62	+61	+60	+59	+58	+57	+56	+55	+54	+53	+52
78	0.957	+66	+65	+64	+64	+63	+62	+61	+60	+59	+58	+57	+56	+55	+54	+53
79	0.989	+67	+66	+66	+65	+64	+63	+62	+61	+60	+59	+58	+57	+56	+55	+54
80	1.022	+68	+68	+67	+66	+66	+65	+64	+63	+62	+61	+60	+59	+58	+57	+56

## 92 METALLURGISTS AND CHEMISTS' HANDBOOK

TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.  
*Continued*

Pressure = 30.0 inches of mercury

Air temp., $t$	Depression of wet-bulb thermometer ( $t - t'$ )															
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	
47	-35															
48	-20	-41														
49	-12	-22	-53													
50	-6	-13	-26													
51	-1	-7	-15	-29												
52	+3	-2	-8	-17	-33											
53	7	+2	-3	-9	-18	-79										
54	10	6	+2	-4	-10	-20	-47									
55	12	9	6	+1	-4	-12	-23	-56								
56	15	12	9	5	+1	-5	-13	-25								
57	17	14	12	9	5	+0	-6	-14	-27							
58	19	17	14	11	8	+4	-1	-6	-15	-30						
59	21	19	17	14	11	8	+4	-1	-7	-16	-33					
60	23	21	19	17	14	11	8	+4	-2	-8	-17	-36				
61	25	23	21	19	17	14	11	8	+3	-2	-8	-18	-40			
62	27	25	23	21	19	16	14	11	7	+3	-2	-9	-19	-45		
63	29	27	25	23	21	19	17	14	11	7	+3	-2	-9	-20	-49	
64	31	29	27	25	23	21	19	17	14	11	7	+3	-3	-10	-21	
65	32	31	29	27	25	24	21	19	17	14	11	7	+3	-3	-10	
66	34	32	31	29	27	26	24	22	19	17	14	11	7	+2	-3	
67	36	34	32	31	29	28	26	24	22	19	17	14	11	7	+2	
68	37	36	34	33	31	29	28	26	24	22	19	17	14	11	7	
69	39	37	36	34	33	31	30	28	26	24	22	19	17	14	11	
70	40	39	38	36	34	33	31	30	28	26	24	22	20	17	14	
71	42	41	39	38	36	35	33	31	30	28	26	24	22	20	17	
72	44	42	41	40	38	37	35	33	32	30	28	26	24	22	20	
73	45	44	43	41	40	38	37	35	34	32	30	28	27	25	22	
74	47	45	44	43	41	40	39	37	35	34	32	30	29	27	25	
75	48	47	46	44	43	42	40	39	37	36	34	32	31	29	27	
76	49	48	47	46	45	43	42	41	39	38	36	34	33	31	29	
77	51	50	49	48	46	45	44	42	41	39	38	36	35	33	31	
78	52	51	50	49	48	46	45	44	43	41	40	38	37	35	33	
79	54	53	52	50	49	48	47	46	44	43	42	40	38	37	35	
80	55	54	53	52	51	50	48	47	46	44	43	42	40	39	37	

$t$	Depression of wet-bulb thermometer ( $t - t'$ )															
	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	
64	-54															
65	-22															
66	-11	-22														
67	-3	-11	-23													
68	+2	-3	-11	-24												
69	7	+2	-3	-11	-24											
70	11	7	+2	-3	-11	-24										
71	14	11	7	+3	-3	-11	-24									
72	17	14	11	7	+3	-3	-11	-24								
73	20	17	15	11	8	+3	-3	-11	-24							
74	23	20	18	15	12	8	+3	-3	-10	-24						
75	25	23	21	18	15	12	8	+4	-2	-10	-23					
76	27	25	23	21	18	15	12	8	+4	-2	-10	-22				
77	29	28	26	23	21	18	16	13	9	+4	-2	-9	-21			
78	31	30	28	26	24	21	19	16	13	9	+5	-1	-9	-20		
79	34	32	30	28	26	24	22	19	16	13	10	+5	-1	-8	-20	
80	36	34	32	30	28	26	24	22	20	17	13	10	+6	±0	-7	



## TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

*Continued*

Pressure = 30.0 inches of mercury

Air temp., $t$	Vapor press., $e$	Depression of wet-bulb thermometer ( $t - t'$ )														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
80	1.022	79	77	76	74	73	72	70	68	67	65	63	62	60	58	56
81	1.056	80	78	77	75	74	73	71	70	68	66	65	63	61	59	57
82	1.091	81	79	78	77	75	74	72	71	69	67	66	64	62	60	59
83	1.127	82	80	79	78	76	75	73	72	70	69	67	65	64	62	60
84	1.163	83	81	80	79	77	76	74	73	71	70	68	66	65	63	61
85	1.201	84	82	81	80	78	77	75	74	72	71	69	68	66	64	62
86	1.241	85	83	82	81	79	78	76	75	73	72	70	69	67	65	64
87	1.281	86	84	83	82	80	79	78	76	75	73	72	70	68	67	65
88	1.322	87	85	84	83	81	80	79	77	76	74	73	71	69	68	66
89	1.364	88	86	85	84	82	81	80	78	77	75	74	72	71	69	67
90	1.408	89	87	86	85	83	82	81	79	78	76	75	73	72	70	69
91	1.453	90	88	87	86	85	83	82	80	79	78	76	75	73	71	70
92	1.499	91	89	88	87	86	84	83	81	80	79	77	76	74	73	71
93	1.546	92	90	89	88	87	85	84	83	81	80	78	77	75	74	72
94	1.595	93	92	90	89	88	86	85	84	82	81	79	78	76	75	73
95	1.645	94	93	91	90	89	87	86	85	83	82	80	79	78	76	74
96	1.696	95	94	92	91	90	88	87	86	84	83	82	80	79	77	76
97	1.749	96	95	93	92	91	89	88	87	85	84	83	81	80	78	77
98	1.803	97	96	94	93	92	90	89	88	87	85	84	82	81	79	78
99	1.859	98	97	95	94	93	92	90	89	88	86	85	83	82	81	79
100	1.916	99	98	96	95	94	93	91	90	89	87	86	85	83	82	80
101	1.975	100	99	97	96	95	94	92	91	90	88	87	86	84	83	81
102	2.035	101	100	98	97	96	95	93	92	91	89	88	87	85	84	83
103	2.097	102	101	99	98	97	96	94	93	92	91	89	88	86	85	84
104	2.160	103	102	100	99	98	97	95	94	93	92	90	89	88	86	85
105	2.225	104	103	101	100	99	98	96	95	94	93	91	90	89	87	86
106	2.292	105	104	102	101	100	99	98	96	95	94	92	91	90	88	87
107	2.360	106	105	103	102	101	100	99	97	96	95	93	92	91	90	88
108	2.431	107	106	104	103	102	101	100	98	97	96	95	93	92	91	89
109	2.503	108	107	105	104	103	102	101	99	98	97	96	94	93	92	90
110	2.576	109	108	106	105	104	103	102	100	99	98	97	95	94	93	91
111	2.652	110	109	108	107	105	104	103	102	100	99	98	96	95	94	93
112	2.730	111	110	109	107	106	105	104	103	101	100	99	98	96	95	94
113	2.810	112	111	110	108	107	106	105	104	102	101	100	99	97	96	95
114	2.891	113	112	111	109	108	107	106	105	103	102	101	100	98	97	96
115	2.975	114	113	112	110	109	108	107	106	104	103	102	101	99	98	97
116	3.061	115	114	113	111	110	109	108	107	105	104	103	102	101	99	98
117	3.148	116	115	114	112	111	110	109	108	107	105	104	103	102	100	99
118	3.239	117	116	115	113	112	111	110	109	108	106	105	104	103	101	100
119	3.331	118	117	116	114	113	112	111	110	109	107	106	105	104	102	101
120	3.425	119	118	117	115	114	113	112	111	110	108	107	106	105	104	102
121	3.522	120	119	118	116	115	114	113	112	111	109	108	107	106	105	103
122	3.621	121	120	119	118	116	115	114	113	112	110	109	108	107	106	104
123	3.723	122	121	120	119	117	116	115	114	113	112	110	109	108	107	106
124	3.827	123	122	121	120	118	117	116	115	114	113	111	110	109	108	107
125	3.933	124	123	122	121	119	118	117	116	115	114	112	111	110	109	108
126	4.042	125	124	123	122	120	119	118	117	116	115	113	112	111	110	109
127	4.154	126	125	124	123	121	120	119	118	117	116	114	113	112	111	110
128	4.268	127	126	125	124	122	121	120	119	118	117	116	114	113	112	111
129	4.385	128	127	126	125	123	122	121	120	119	118	117	115	114	113	112
130	4.504	129	128	127	126	124	123	122	121	120	119	118	116	115	114	113
131	4.627	130	129	128	127	125	124	123	122	121	120	119	117	116	115	114
132	4.752	131	130	129	128	126	125	124	123	122	121	120	119	117	116	115
133	4.880	132	131	130	129	127	126	125	124	123	122	121	120	118	117	116
134	5.011	133	132	131	130	129	127	126	125	124	123	122	121	119	118	117
135	5.145	134	133	132	131	130	128	127	126	125	124	123	122	120	119	118
136	5.282	135	134	133	132	131	129	128	127	126	125	124	123	121	120	119
137	5.422	136	135	134	133	132	130	129	128	127	126	125	124	123	121	120
138	5.565	137	136	135	134	133	131	130	129	128	127	126	125	124	122	121
139	5.712	138	137	136	135	134	132	131	130	129	128	127	126	125	123	122
140	5.862	139	138	137	136	135	133	132	131	130	129	128	127	126	124	123

## TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

*Continued*

Pressure = 30.0 inches of mercury

Air temp., $t$	Vapor press., $e$	Depression of wet-bulb thermometer ( $t - t'$ )															
		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
80	1.022	54	52	50	47	44	42	39	36	32	28	24	20	13	6	-7	
81	1.056	55	53	51	49	46	43	41	38	34	31	27	22	17	10	+7	
82	1.091	57	55	52	50	48	45	42	39	36	33	29	25	20	14	+7	
83	1.127	58	56	54	52	49	47	44	41	38	35	31	27	23	18	11	
84	1.163	59	57	55	53	51	48	46	43	40	37	34	30	26	21	15	
85	1.201	61	59	57	54	52	50	48	45	42	39	36	32	28	24	19	
86	1.241	62	60	58	56	54	52	49	47	44	41	38	34	31	27	22	
87	1.281	63	61	59	57	55	53	51	48	46	43	40	36	33	29	25	
88	1.322	64	62	61	59	57	55	52	50	47	45	42	38	35	31	27	
89	1.364	66	64	62	60	58	56	54	51	49	46	44	41	37	34	30	
90	1.408	67	65	63	61	59	57	55	53	51	48	45	43	39	36	32	
91	1.453	68	66	65	63	61	59	57	55	52	50	47	44	41	38	35	
92	1.499	69	68	66	64	62	60	58	56	54	51	49	46	43	40	37	
93	1.546	71	69	67	65	63	62	60	58	55	53	51	48	45	42	39	
94	1.595	72	70	68	67	65	63	61	59	57	55	52	50	47	44	41	
95	1.645	73	71	70	68	66	64	62	60	58	56	54	52	49	46	43	
96	1.696	74	72	71	69	67	66	64	62	60	58	55	53	51	48	45	
97	1.749	75	74	72	70	69	67	65	63	61	59	57	55	52	50	47	
98	1.803	76	75	73	72	70	68	66	64	63	61	58	56	54	52	49	
99	1.859	78	76	74	73	71	69	68	66	64	62	60	58	56	53	51	
100	1.916	79	77	76	74	72	71	69	67	65	63	61	59	57	55	52	
101	1.975	80	78	77	75	74	72	70	69	67	65	63	61	59	57	55	
102	2.035	81	80	78	76	75	73	72	70	68	66	64	62	60	58	56	
103	2.097	82	81	79	78	76	74	73	71	69	68	66	64	62	60	57	
104	2.160	83	82	80	79	77	76	74	72	71	69	67	65	63	61	59	
105	2.225	84	83	82	80	78	77	75	74	72	70	68	67	65	63	61	
106	2.292	86	84	83	81	80	78	77	75	73	72	70	68	66	64	62	
107	2.360	87	85	84	82	81	79	78	76	75	73	71	69	67	66	64	
108	2.431	88	86	85	84	82	81	79	77	76	74	72	71	69	67	65	
109	2.503	89	88	86	85	83	82	80	79	77	75	74	72	70	68	66	
110	2.576	90	89	87	86	84	83	81	80	78	77	75	73	72	70	68	
111	2.652	91	90	88	87	86	84	83	81	80	78	76	75	73	71	69	
112	2.730	92	91	89	88	87	85	84	82	81	79	78	76	74	72	71	
113	2.810	93	92	91	89	88	86	85	84	82	81	79	78	76	74	72	
114	2.891	94	93	92	90	89	88	86	85	83	82	80	79	77	75	73	
115	2.975	96	94	93	92	90	89	87	86	84	83	81	80	78	76	75	
116	3.061	97	95	94	93	91	90	88	87	86	84	83	81	79	78	76	
117	3.148	98	96	95	94	92	91	90	88	87	85	84	82	81	79	77	
118	3.239	99	98	96	95	94	92	91	89	88	86	85	84	82	80	79	
119	3.331	100	99	97	96	95	93	92	91	89	88	86	85	83	82	80	
120	3.425	101	100	98	97	96	94	93	92	90	89	87	86	84	83	81	
121	3.522	102	101	100	98	97	96	94	93	91	90	89	87	86	84	83	
122	3.621	103	102	101	99	98	97	95	94	93	91	90	88	87	85	84	
123	3.723	104	103	102	100	99	98	96	95	94	92	91	90	88	87	85	
124	3.827	105	104	103	102	100	99	98	96	95	94	92	91	89	88	86	
125	3.933	106	105	104	103	101	100	99	97	96	95	93	92	90	89	88	
126	4.042	107	106	105	104	102	101	100	99	97	96	95	93	92	90	89	
127	4.154	109	107	106	105	104	102	101	100	99	97	96	94	93	91	90	
128	4.268	110	108	107	106	105	103	102	101	99	98	97	95	94	93	91	
129	4.385	111	109	108	107	106	104	103	102	101	99	98	97	95	94	92	
130	4.504	112	110	109	108	107	106	104	103	102	100	99	98	96	95	94	
131	4.627	113	112	110	109	108	107	105	104	103	101	100	99	97	96	95	
132	4.752	114	113	111	110	109	108	106	105	104	103	101	100	99	97	96	
133	4.880	115	114	112	111	110	109	108	106	105	104	102	101	100	98	97	
134	5.011	116	115	114	112	111	110	109	107	106	105	104	102	101	100	98	
135	5.145	117	116	115	113	112	111	110	108	107	106	105	104	102	101	100	
136	5.282	118	117	116	114	113	112	111	110	108	107	106	105	103	102	101	
137	5.422	119	118	117	116	114	113	112	111	109	108	107	106	104	103	102	
138	5.565	120	119	118	117	115	114	113	112	110	109	108	107	105	104	103	
139	5.712	121	120	119	118	116	115	114	113	112	110	109	108	107	105	104	
140	5.862	122	121	120	119	117	116	115	114	113	111	110	109	108	106	105	

# PHYSICAL CONSTANTS

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## TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

*Continued*

Pressure = 30.0 inches of mercury

At- temp., t	Vapor press., e	Depression of wet-bulb thermometer (t - t')														
		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
80	1.022	-53														
81	1.056	-18														
82	1.091	-6	-43													
83	1.127	+2	-15													
84	1.163	8	-4	-33												
85	1.201	12	+3	-12												
86	1.241	16	9	-2	-27											
87	1.281	20	13	+5	-10											
88	1.322	23	17	10	±0	-22										
89	1.364	26	21	15	+6	-7										
90	1.408	28	24	19	11	+1	-17									
91	1.453	31	27	22	16	8	-4	-40								
92	1.499	33	29	25	20	13	+4	-13								
93	1.546	36	32	28	23	17	10	-2	-23							
94	1.595	38	34	30	26	21	14	+6	-9							
95	1.645	40	37	33	29	24	19	11	+1	-20						
96	1.696	42	39	35	31	27	22	16	8	-5						
97	1.749	44	41	38	34	30	25	20	13	+3	-15					
98	1.803	46	43	40	36	32	28	23	17	10	-2	-33				
99	1.859	48	45	42	39	35	31	26	21	15	+6	-10				
100	1.916	50	47	44	41	37	33	29	25	19	12	+1	-22			
101	1.975	52	49	46	43	40	36	32	28	23	17	8	-5			
102	2.035	53	51	48	45	42	38	35	31	26	21	14	+4	-14		
103	2.097	55	53	50	47	44	41	37	33	29	24	18	11	-2	-32	
104	2.160	57	54	52	49	46	43	40	36	32	27	22	16	+7	-9	
105	2.225	58	56	54	51	48	45	42	38	34	30	26	20	13	+2	-20
106	2.292	60	58	55	53	50	47	44	41	37	33	29	24	18	9	+5
107	2.360	62	59	57	55	52	49	46	43	40	36	32	27	22	15	+4
108	2.431	63	61	59	56	54	51	48	45	42	39	35	30	25	20	12
109	2.503	64	62	60	58	56	53	50	47	44	41	37	33	29	23	17
110	2.576	66	64	62	60	57	55	52	50	47	43	40	36	32	27	21
111	2.652	67	65	63	61	59	57	54	52	49	46	42	39	35	30	25
112	2.730	69	67	65	63	61	58	56	54	51	48	45	41	37	33	29
113	2.810	70	68	66	64	62	60	58	55	50	47	44	40	36	32	28
114	2.891	72	70	68	66	64	62	59	57	55	52	49	46	43	39	35
115	2.975	73	71	69	67	65	63	61	59	56	54	51	48	45	42	38
116	3.061	74	73	71	69	67	65	63	60	58	56	53	50	47	44	40
117	3.148	76	74	72	70	68	66	64	62	60	58	55	52	49	46	43
118	3.239	77	75	74	72	70	68	66	64	62	59	57	54	51	49	45
119	3.331	78	77	75	73	71	69	67	65	63	61	59	56	53	51	48
120	3.425	80	78	76	75	73	71	69	67	65	63	60	58	55	53	50
121	3.522	81	79	78	76	74	72	70	68	66	64	62	60	57	55	52
122	3.621	82	81	79	77	76	74	72	70	68	66	64	62	59	57	54
123	3.723	84	82	80	79	77	75	73	71	69	67	65	63	61	58	56
124	3.827	85	83	82	80	78	77	75	73	71	69	67	65	63	60	58
125	3.933	86	84	83	81	80	78	76	74	72	71	69	66	64	62	60
126	4.042	87	86	84	83	81	79	78	76	74	72	70	68	66	64	62
127	4.154	88	87	85	84	82	81	79	77	75	74	72	70	68	65	63
128	4.268	90	88	87	85	84	82	80	79	77	75	73	71	69	67	65
129	4.385	91	89	88	86	85	83	82	80	78	76	75	73	71	69	67
130	4.504	92	91	89	88	86	85	83	81	80	78	76	74	72	70	68
131	4.627	93	92	90	89	87	86	84	83	81	79	77	76	74	72	70
132	4.752	94	93	92	90	89	87	86	84	82	81	79	77	75	73	71
133	4.880	96	94	93	91	90	88	87	85	84	82	80	78	77	75	73
134	5.011	97	95	94	93	91	90	88	87	85	83	82	80	78	76	74
135	5.145	96	97	95	94	92	91	89	88	86	85	83	81	80	78	76
136	5.282	99	98	96	95	94	92	91	89	88	86	84	83	81	79	77
137	5.422	100	99	98	96	95	93	92	90	89	87	86	84	82	81	79
138	5.565	101	100	99	97	96	95	93	92	90	89	87	85	84	82	80
139	5.712	103	101	100	99	97	96	94	93	91	90	88	87	85	83	82
140	5.862	104	102	101	100	98	97	96	94	93	91	90	88	86	85	83

# TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT

*Continued*

Pressure = 23.0 inches of mercury

Air temp., $t$	Depression of wet-bulb thermometer ( $t - t'$ )														
	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0
-2	-49														
-1	-40	-51													
0	-33	-41	-52												
+1	-29	-33	-42	-54											
2	-25	-29	-34	-43	-56										
3	-22	-25	-29	-34	-43	-58									
4	-19	-22	-25	-29	-35	-44	-59								
5	-17	-19	-22	-25	-29	-35	-45	-60							
6	-14	-17	-19	-22	-25	-30	-35	-45	-60						
7	-12	-14	-16	-19	-22	-25	-30	-35	-45						
8	-10	-12	-14	-16	-19	-22	-25	-29	-35	-45					
9	-8	-10	-12	-14	-16	-19	-21	-25	-29	-35	-44	-60			
10	-6	-8	-10	-12	-14	-16	-18	-21	-24	-29	-34	-43	-59		
11	-5	-6	-7	-9	-11	-13	-15	-18	-20	-24	-28	-33	-42	-56	
12	-3	-4	-5	-7	-9	-11	-13	-15	-17	-20	-23	-27	-32	-40	-53
13	-1	-2	-4	-5	-7	-8	-10	-12	-14	-17	-19	-22	-26	-31	-38
14	± 0	-1	-2	-3	-5	-6	-8	-9	-11	-13	-16	-18	-21	-25	-29
15	+ 2	+ 1	± 0	-1	-3	-4	-5	-7	-9	-11	-13	-15	-17	-20	-24
16	4	2	+ 2	± 0	-1	-2	-3	-5	-6	-8	-10	-12	-14	-16	-19
17	5	4	3	+ 2	+ 1	± 0	-2	-3	-4	-5	-7	-9	-11	-13	-15
18	7	6	5	4	3	+ 2	± 0	-1	-2	-3	-5	-6	-8	-10	-12
19	8	7	6	5	4	3	+ 2	+ 1	0	-1	-3	-4	-5	-7	-9
20	9	9	8	7	6	5	4	3	+ 2	+ 1	-1	-2	-3	-5	-6

$t$	$(t - t')$									
	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0
13	-49									
14	-36	-47								
15	-28	-34	-44	-59						
16	-22	-27	-32	-40	-53					
17	-18	-21	-25	-29	-36	-47				
18	-14	-17	-20	-23	-27	-33	-42	-58		
19	-11	-13	-16	-18	-21	-25	-30	-37	-49	
20	-8	-10	-12	-14	-17	-20	-23	-28	-33	-44

TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

*Continued*

Pressure = 23.0 inches of mercury

Air temp., <i>t</i>	Vapor press., <i>s</i>	Depression of wet-bulb thermometer ( <i>t</i> - <i>t'</i> )															
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
20	0.103	19	17	16	14	12	10	8	6	3	1	-3	-6	-11	-17	-26	-44
21	0.108	20	18	17	15	13	12	10	8	5	2	-1	-4	-8	-13	-20	-30
22	0.113	21	19	18	16	15	13	11	9	7	4	1	-2	-5	-10	-15	-23
23	0.118	22	20	19	17	16	14	12	10	8	6	3	± 0	-3	-7	-12	-18
24	0.124	23	21	20	19	17	15	14	12	10	8	5	2	-1	-4	-8	-14
25	0.130	24	23	21	20	18	17	15	13	11	9	7	4	1	-2	-5	-10
26	0.136	25	24	22	21	20	18	16	15	13	11	9	6	4	1	-3	-7
27	0.143	26	25	23	22	21	19	18	16	14	12	10	8	6	3	± 0	-4
28	0.150	27	26	24	23	22	20	19	17	16	14	12	10	8	5	2	-1
29	0.157	28	27	26	24	23	22	20	19	17	15	13	11	9	7	4	1
30	0.164	29	28	27	25	24	23	21	20	18	17	15	13	11	9	7	4
31	0.172	30	29	28	27	25	24	23	21	20	18	17	15	13	11	8	6
32	0.180	31	30	29	28	26	25	24	23	21	20	18	16	14	12	10	8
33	0.187	32	31	30	29	28	26	25	24	22	21	19	18	16	14	12	10
34	0.195	33	32	31	30	29	28	26	25	24	22	21	19	18	16	14	12
35	0.203	34	33	32	31	30	29	28	26	25	24	22	21	19	17	16	14
36	0.211	35	34	33	32	31	30	29	27	26	25	24	22	21	19	17	15
37	0.219	36	35	34	33	32	31	30	28	27	26	25	24	22	20	19	17
38	0.228	37	36	35	34	33	32	31	30	28	27	26	25	23	22	20	19
39	0.237	38	37	36	35	34	33	32	31	30	28	27	26	25	23	22	20
40	0.247	39	38	37	36	35	34	33	32	31	30	28	27	26	25	23	22
41	0.256	40	39	38	37	36	35	34	33	32	31	29	28	27	26	24	23
42	0.266	41	40	39	38	37	36	35	34	33	32	31	29	28	27	26	24
43	0.277	42	41	40	39	38	37	36	35	34	33	32	31	29	28	27	26
44	0.287	43	42	41	40	39	38	37	36	35	34	33	32	31	29	28	27
45	0.298	44	43	42	41	40	39	38	37	36	35	34	33	32	31	29	28
46	0.310	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30
47	0.322	46	45	44	43	42	41	40	38	37	36	35	34	33	32	31	30
48	0.334	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
49	0.347	48	47	46	45	44	43	42	41	40	39	38	37	36	34	33	32
50	0.360	49	48	47	46	45	44	43	42	41	40	39	38	37	36	34	33
51	0.373	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	34
52	0.387	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36
53	0.402	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37
54	0.417	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38
55	0.432	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39
56	0.448	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40
57	0.465	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41
58	0.482	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42
59	0.499	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43
60	0.517	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44
61	0.536	60	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46
62	0.555	61	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47
63	0.575	62	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
64	0.595	63	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49
65	0.616	64	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50
66	0.638	65	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51
67	0.661	66	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52
68	0.684	67	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53
69	0.707	68	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54
70	0.732	69	69	68	67	66	65	64	63	62	61	60	59	58	57	56	55
71	0.757	70	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56
72	0.783	71	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57
73	0.810	72	72	71	70	69	68	67	66	65	64	63	62	61	60	59	58
74	0.838	73	73	72	71	70	69	68	67	66	65	64	63	62	61	60	59
75	0.866	74	74	73	72	71	70	69	68	67	66	65	64	63	62	61	60
76	0.896	75	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61
77	0.926	76	76	75	74	73	72	71	70	69	68	67	66	65	64	63	62
78	0.957	77	77	76	75	74	73	72	71	70	69	68	67	66	65	64	63
79	0.989	78	78	77	76	75	74	73	72	71	70	69	68	67	66	65	64
80	1.022	79	79	78	77	76	75	74	73	72	71	70	69	68	67	66	65

## 100 METALLURGISTS AND CHEMISTS' HANDBOOK

TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.  
*Continued*

Pressure = 23.0 inches of mercury

Air temp., $t$	Vapor press., $e$	Depression of wet-bulb thermometer ( $t - t'$ )															
		8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0
22	0.113	-37															
23	0.118	-28	-50														
24	0.124	-21	-32														
25	0.130	-16	-24	-42													
26	0.136	-12	-18	-29	-50												
27	0.143	-8	-14	-21	-34												
28	0.150	-5	-10	-16	-24	-43											
29	0.157	-2	-6	-11	-18	-29	-57										
30	0.164	+0	-3	-7	-13	-21	-33										
31	0.172	+3	+0	-4	-9	-15	-23	-40									
32	0.180	+5	+2	-1	-5	-10	-16	-26	-50								
33	0.187	8	5	+2	-2	-6	-11	-18	-30								
34	0.195	10	7	4	+1	-3	-7	-12	-20	-34							
35	0.203	12	9	7	+4	+0	-3	-8	-14	-22	-40						
36	0.211	13	11	9	6	+3	+0	-4	-9	-15	-25	-47					
37	0.219	15	13	11	9	6	+3	-1	-5	-10	-17	-28	-60				
38	0.228	17	15	13	11	8	6	+2	-1	-6	-11	-18	-31				
39	0.237	19	17	15	13	11	8	5	+2	-2	-6	-12	-20	-34			
40	0.247	20	19	17	15	13	10	8	5	+1	-2	-7	-13	-22	-39		
41	0.256	22	20	19	17	15	12	10	8	5	+1	-3	-8	-14	-23	-45	
42	0.266	23	22	20	18	17	14	12	10	7	4	+1	-3	-8	-15	-25	-50
43	0.277	24	23	22	20	18	16	14	12	10	7	4	+0	-4	-9	-16	-27
44	0.287	26	24	23	22	20	18	16	14	12	10	7	+4	+0	-4	-10	-17
45	0.298	27	26	24	23	21	20	18	16	14	12	10	7	+4	+0	-5	-10
46	0.310	28	27	26	24	23	21	20	18	16	14	12	10	7	+3	-1	-5
47	0.322	30	28	27	26	24	23	21	20	18	16	14	12	9	7	+3	-1
48	0.334	31	30	28	27	26	24	23	21	20	18	16	14	12	9	6	+3
49	0.347	32	31	30	28	27	26	24	23	21	20	18	16	14	11	9	6
50	0.360	33	32	31	30	28	27	26	24	23	21	20	18	16	14	11	9
51	0.373	34	33	32	31	30	29	27	26	24	23	21	20	18	16	14	11
52	0.387	36	35	34	32	31	30	29	27	26	24	23	21	20	18	16	14
53	0.402	37	36	35	34	32	31	30	29	27	26	25	23	21	20	18	16
54	0.417	38	37	36	35	34	32	31	30	29	27	26	25	23	21	20	18
55	0.432	40	39	38	36	35	34	32	31	30	29	27	26	25	23	22	20
56	0.448	41	40	39	38	36	35	34	33	31	30	29	28	26	25	23	22
57	0.465	42	41	40	39	38	37	35	34	33	32	30	29	28	26	25	23
58	0.482	43	42	41	40	39	38	37	36	34	33	32	31	29	28	26	25
59	0.499	45	44	43	42	40	39	38	37	36	35	33	32	31	29	28	27
60	0.517	46	45	44	43	42	41	40	38	37	36	35	33	32	31	30	28
61	0.536	47	46	45	44	43	42	41	40	39	37	36	35	34	32	31	30
62	0.555	48	47	46	45	44	43	42	41	40	39	38	36	35	34	32	31
63	0.575	49	48	47	46	45	44	43	42	41	40	39	38	36	35	34	33
64	0.595	50	50	49	48	47	46	45	44	43	42	41	39	38	37	36	34
65	0.616	52	51	50	49	48	47	46	45	44	43	42	41	40	38	37	36
66	0.638	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38
67	0.661	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39
68	0.684	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40
69	0.707	56	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42
70	0.732	57	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43
71	0.757	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44
72	0.783	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45
73	0.810	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46
74	0.838	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47
75	0.866	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
76	0.898	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49
77	0.926	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50
78	0.957	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51
79	0.989	67	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53
80	1.022	69	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54

# PHYSICAL CONSTANTS

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## TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

Continued

Pressure = 23.0 inches of mercury

Air temp. $t$	Depression of wet-bulb thermometer ( $t - t'$ )															
	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0
44	-29															
45	-18	-31														
46	-11	-19	-33													
47	-5	-11	-20	-35												
48	-1	-5	-12	-20	-38											
49	+3	-1	-6	-12	-21	-40										
50	6	+3	-1	-6	-12	-21	-42									
51	9	6	+2	-2	-6	-12	-22	-44								
52	11	9	6	+2	-2	-7	-13	-22	-46							
53	14	11	9	6	+2	-2	-7	-14	-23	-47						
54	18	13	11	9	6	+2	-2	-7	-14	-24	-50					
55	18	16	14	11	8	5	+2	-2	-7	-14	-25	-55				
56	20	18	16	14	11	8	5	+2	-2	-8	-15	-26	-60			
57	22	20	18	16	14	11	8	5	+2	-3	-8	-15	-26			
58	23	22	20	18	16	14	11	9	5	+2	-3	-8	-15	-27		
59	25	24	22	20	18	16	14	11	9	5	+2	-3	-8	-16	-28	
60	27	25	24	22	20	18	16	14	11	9	6	+2	-3	-8	-16	-28
61	28	27	25	24	22	20	18	16	14	12	9	6	+2	-3	-8	-18
62	30	28	27	26	24	22	20	19	17	14	12	9	6	+2	-3	-6
63	32	30	29	27	26	24	22	21	19	17	14	12	9	6	+2	-3
64	33	32	30	29	28	26	24	23	21	19	17	15	12	9	6	+2
65	35	33	32	31	29	28	26	25	23	21	19	17	15	12	10	6
66	36	35	34	32	31	29	28	27	25	23	22	19	17	15	12	10
67	38	36	35	34	32	31	30	28	27	25	24	22	20	18	15	13
68	39	38	37	35	34	33	31	30	28	27	25	24	22	20	18	16
69	41	39	38	37	36	34	33	32	30	29	27	26	24	22	20	18
70	42	41	40	38	37	36	35	33	32	31	29	27	26	24	22	20
71	44	42	41	40	39	38	36	35	34	32	31	29	28	26	25	23
72	45	44	43	42	40	39	38	37	35	34	32	31	29	28	27	25
73	46	45	44	43	42	41	40	38	37	36	34	33	31	30	28	27
74	48	47	46	45	43	42	41	40	38	37	36	34	33	32	30	29
75	49	48	47	46	45	44	43	42	40	39	38	36	35	34	32	31
76	50	49	48	47	46	45	44	43	42	41	39	38	37	35	34	32
77	52	51	50	49	48	47	46	44	43	42	41	40	38	37	36	34
78	53	52	51	50	49	48	47	46	45	44	43	41	40	39	37	36
79	54	54	53	52	51	50	49	47	46	45	44	43	42	40	39	38
80	56	55	54	53	52	51	50	49	48	47	46	44	43	42	41	40

$t$	Depression of wet-bulb thermometer ( $t - t'$ )															
	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5	32.0
61	-29															
62	-16	-29														
63	-8	-16	-28													
64	-2	-7	-15	-28												
65	+2	-2	-7	-15	-28											
66	7	+3	-2	-7	-15	-27										
67	10	7	+3	-1	-7	-14	-27									
68	13	10	7	+3	-1	-6	-14	-26								
69	16	13	11	8	+4	-1	-6	-13	-25							
70	18	16	14	11	8	+4	± 0	-5	-13	-24						
71	21	19	17	14	11	8	+5	± 0	-5	-12	-23	-54				
72	23	21	19	17	14	12	9	+5	+1	-4	-11	-22	-50			
73	25	23	22	20	17	15	12	9	6	+1	-4	-11	-20	-45		
74	27	26	24	22	20	18	15	12	10	6	+2	-3	-10	-19	-37	
75	29	28	26	24	22	20	18	15	13	10	7	+2	-3	-9	-18	-37
76	31	29	28	26	24	23	21	18	16	13	10	7	+3	-2	-8	-17
77	33	31	30	28	27	25	23	21	19	16	14	11	8	+4	-1	0
78	35	33	32	30	29	27	25	23	21	19	17	14	11	8	+4	± 7
79	37	35	33	32	31	29	27	26	24	22	20	17	15	12	9	+5
80	38	37	35	34	32	31	29	28	26	24	22	20	18	15	12	9

## 102 METALLURGISTS AND CHEMISTS' HANDBOOK

## TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

*Continued*

Pressure = 23.0 inches of mercury

Air temp., $t$	Vapor press., $e$	Depression of wet-bulb thermometer ( $t - t'$ )															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80	1.022	79	77	76	75	73	72	71	69	68	66	65	63	62	60	58	57
81	1.056	80	78	77	76	75	73	72	70	69	67	66	64	63	61	60	58
82	1.091	81	79	78	77	76	74	73	71	70	69	67	66	64	62	61	59
83	1.127	82	81	79	78	77	75	74	72	71	70	68	67	65	64	62	60
84	1.163	83	82	80	79	78	76	75	74	72	71	69	68	66	65	63	62
85	1.201	84	83	81	80	79	77	76	75	73	72	70	69	67	66	64	63
86	1.241	85	84	82	81	80	78	77	76	74	73	72	70	69	67	66	64
87	1.281	86	85	83	82	81	79	78	77	75	74	73	71	70	68	67	65
88	1.322	87	86	84	83	82	80	79	78	76	75	74	72	71	69	68	66
89	1.364	88	87	85	84	83	82	80	79	78	76	75	73	72	71	69	67
90	1.408	89	88	86	85	84	83	81	80	79	77	76	75	73	72	70	69
91	1.453	90	89	87	86	85	84	82	81	80	78	77	76	74	73	71	70
92	1.499	91	90	88	87	86	85	83	82	81	79	78	77	75	74	72	71
93	1.546	92	91	89	88	87	86	84	83	82	81	79	78	76	75	74	72
94	1.595	93	92	90	89	88	87	85	84	83	82	81	79	78	76	75	73
95	1.645	94	93	91	90	89	88	87	85	84	83	81	80	79	77	76	74
96	1.696	95	94	92	91	90	89	88	86	85	84	82	81	80	78	77	76
97	1.749	96	95	93	92	91	90	89	87	86	85	83	82	81	79	78	77
98	1.803	97	96	94	93	92	91	90	88	87	86	85	83	82	81	79	78
99	1.859	98	97	95	94	93	92	91	89	88	87	86	84	83	82	80	79
100	1.916	99	98	96	95	94	93	92	90	89	88	87	85	84	83	81	80
101	1.975	100	99	98	96	95	94	93	92	90	89	88	86	85	84	83	81
102	2.035	101	100	99	97	96	95	94	93	91	90	89	88	86	85	84	82
103	2.097	102	101	100	98	97	96	95	94	92	91	90	89	87	86	85	83
104	2.160	103	102	101	99	98	97	96	95	93	92	91	90	88	87	86	85
105	2.225	104	103	102	100	99	98	97	96	94	93	92	91	89	88	87	86
106	2.292	105	104	103	101	100	99	98	97	95	94	93	92	91	89	88	87
107	2.360	106	105	104	102	101	100	99	98	97	95	94	93	92	91	89	88
108	2.431	107	106	105	103	102	101	100	99	98	96	95	94	93	91	90	89
109	2.503	108	107	106	104	103	102	101	100	99	97	96	95	94	92	91	90
110	2.576	109	108	107	105	104	103	102	101	100	98	97	96	95	94	92	91
111	2.652	110	109	108	106	105	104	103	102	101	99	98	97	96	95	93	92
112	2.730	111	110	109	108	106	105	104	103	102	101	99	98	97	96	94	93
113	2.810	112	111	110	109	107	106	105	104	103	102	100	99	98	97	96	94
114	2.891	113	112	111	110	108	107	106	105	104	103	101	100	99	98	97	95
115	2.975	114	113	112	111	109	108	107	106	105	104	102	101	100	99	98	96
116	3.061	115	114	113	112	110	109	108	107	106	105	103	102	101	100	99	97
117	3.148	116	115	114	113	111	110	109	108	107	106	105	103	102	101	100	99
118	3.239	117	116	115	114	112	111	110	109	108	107	106	105	103	102	101	100
119	3.331	118	117	116	115	113	112	111	110	109	108	107	106	104	103	102	101
120	3.425	119	118	117	116	114	113	112	111	110	109	108	107	105	104	103	102
121	3.522	120	119	118	117	115	114	113	112	111	110	109	108	106	105	104	103
122	3.621	121	120	119	118	116	115	114	113	112	111	110	109	108	106	105	104
123	3.723	122	121	120	119	118	116	115	114	113	112	111	110	109	107	106	105
124	3.827	123	122	121	120	119	117	116	115	114	113	112	111	110	109	107	106
125	3.933	124	123	122	121	120	118	117	116	115	114	113	112	111	110	109	108
126	4.042	125	124	123	122	121	119	118	117	116	115	114	113	112	111	110	109
127	4.154	126	125	124	123	122	120	119	118	117	116	115	114	113	112	111	110
128	4.268	127	126	125	124	123	121	120	119	118	117	116	115	114	113	112	111
129	4.385	128	127	126	125	124	122	121	120	119	118	117	116	115	114	113	112
130	4.504	129	128	127	126	125	123	122	121	120	119	118	117	116	115	114	113
131	4.627	130	129	128	127	126	124	123	122	121	120	119	118	117	116	115	114
132	4.752	131	130	129	128	127	125	124	123	122	121	120	119	118	117	116	115
133	4.880	132	131	130	129	128	126	125	124	123	122	121	120	119	118	117	116
134	5.011	133	132	131	130	129	127	126	125	124	123	122	121	120	119	118	117
135	5.145	134	133	132	131	130	129	127	126	125	124	123	122	121	120	119	118
136	5.282	135	134	133	132	131	130	128	127	126	125	124	123	122	121	120	119
137	5.422	136	135	134	133	132	131	129	128	127	126	125	124	123	122	121	120
138	5.565	137	136	135	134	133	132	130	129	128	127	126	125	124	123	122	121
139	5.712	138	137	136	135	134	133	132	130	129	128	127	126	125	124	123	122
140	5.862	139	138	137	136	135	134	133	131	130	129	128	127	126	125	124	123



# PHYSICAL CONSTANTS

103

## TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

Continued

Pressure = 23.0 inches of mercury

Air temp., $t$	Vapor press., $e$	Depression of wet-bulb thermometer ( $t - t'$ )															
		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
80	1.022	55	53	51	49	47	44	42	40	37	34	31	28	24	20	15	9
81	1.056	56	54	52	50	48	46	44	41	39	36	33	30	27	23	18	13
82	1.091	57	56	54	52	50	47	45	43	40	38	35	32	29	25	21	16
83	1.127	59	57	55	53	51	49	47	44	42	40	37	34	31	27	24	19
84	1.163	60	58	56	54	52	50	48	46	44	41	39	36	32	29	26	22
85	1.201	61	59	58	56	54	52	50	48	45	43	40	38	35	31	28	25
86	1.241	62	61	59	57	55	53	51	49	47	45	42	40	37	34	30	27
87	1.281	64	62	60	58	57	55	53	51	48	46	44	41	39	36	32	29
88	1.322	65	63	61	60	58	56	54	52	50	48	46	43	40	38	35	31
89	1.364	66	64	63	61	59	57	55	54	52	49	47	45	42	39	37	33
90	1.408	67	66	64	62	60	59	57	55	53	51	49	46	44	41	38	35
91	1.453	68	67	65	63	62	60	58	56	54	52	50	48	46	43	40	37
92	1.499	69	68	66	65	63	61	59	58	56	54	52	50	47	45	42	39
93	1.546	71	69	68	66	64	63	61	59	57	55	53	51	49	46	44	42
94	1.595	72	70	69	67	66	64	62	60	59	57	55	53	50	48	46	43
95	1.645	73	72	70	68	67	65	63	62	60	58	56	54	52	50	48	45
96	1.696	74	73	71	70	68	66	65	63	61	60	58	56	54	51	49	47
97	1.749	75	74	72	71	69	68	66	64	63	61	59	57	55	53	51	48
98	1.803	76	75	74	72	70	69	67	66	64	62	60	58	56	54	52	50
99	1.859	78	76	75	73	72	70	69	67	65	64	62	60	58	56	54	52
100	1.916	79	77	76	74	73	71	70	68	67	65	63	61	59	58	56	53
101	1.975	80	78	77	76	74	73	71	69	68	66	64	63	61	59	57	55
102	2.035	81	80	78	77	75	74	72	71	69	67	66	64	62	60	58	56
103	2.097	82	81	79	78	76	75	73	73	70	69	67	65	64	62	60	58
104	2.160	83	82	80	79	78	76	75	73	72	70	68	67	65	63	61	59
105	2.225	84	83	82	80	79	77	76	74	73	71	70	68	66	64	63	61
106	2.292	85	84	83	81	80	78	77	76	74	72	71	69	68	66	64	62
107	2.360	86	85	84	82	81	80	78	77	75	74	72	71	69	67	66	64
108	2.431	88	86	85	84	82	81	79	78	76	75	73	72	70	69	67	65
109	2.503	89	87	86	85	83	82	81	79	78	76	75	73	72	70	68	66
110	2.576	90	88	87	86	84	83	82	80	79	77	76	74	73	71	69	68
111	2.652	91	90	88	87	86	84	83	81	80	79	77	76	74	72	71	69
112	2.730	92	91	89	88	87	85	84	83	81	80	78	77	75	74	72	70
113	2.810	93	92	90	89	88	87	85	84	82	81	80	78	76	75	73	72
114	2.891	94	93	92	90	89	88	86	85	84	82	81	79	78	76	75	73
115	2.975	95	94	93	91	90	89	87	86	85	83	82	80	79	77	76	74
116	3.061	96	95	94	92	91	90	89	87	86	84	83	82	80	79	77	76
117	3.148	97	96	95	94	92	91	90	88	87	86	84	83	81	80	78	77
118	3.239	98	97	96	95	93	92	91	89	88	87	85	84	83	81	80	78
119	3.331	99	98	97	96	94	93	92	90	89	88	87	85	84	82	81	79
120	3.425	101	99	98	97	96	94	93	92	90	89	88	86	85	84	82	81
121	3.522	102	100	99	98	97	95	94	93	92	90	89	88	86	85	83	82
122	3.621	103	101	100	99	98	96	95	94	93	91	90	89	87	86	84	83
123	3.723	104	102	101	100	99	98	96	95	94	92	91	90	88	87	86	84
124	3.827	105	104	102	101	100	99	97	96	95	94	92	91	90	88	87	85
125	3.933	106	105	103	102	101	100	99	97	96	95	93	92	91	89	88	87
126	4.042	107	106	104	103	102	101	100	98	97	96	95	93	92	91	89	88
127	4.154	108	107	106	104	103	102	101	99	98	97	96	94	93	92	90	89
128	4.268	109	108	107	105	104	103	102	101	99	98	97	95	94	93	92	90
129	4.385	110	109	108	106	105	104	103	102	100	99	98	97	95	94	93	91
130	4.504	111	110	109	108	106	105	104	103	101	100	99	98	96	95	94	92
131	4.627	112	111	110	109	107	106	105	104	103	101	100	99	98	96	95	94
132	4.752	113	112	111	110	108	107	106	105	104	102	101	100	99	97	96	95
133	4.880	114	113	112	111	110	108	107	106	105	104	102	101	100	99	97	96
134	5.011	115	114	113	112	111	109	108	107	106	105	103	102	101	100	98	97
135	5.145	116	115	114	113	112	111	109	108	107	106	104	103	102	101	99	98
136	5.282	117	116	115	114	113	112	110	109	108	107	106	104	103	102	101	99
137	5.422	118	117	116	115	114	113	111	110	109	108	107	105	104	103	102	100
138	5.565	119	118	117	116	115	114	112	111	110	109	108	107	105	104	103	102
139	5.712	120	119	118	117	116	115	114	112	111	110	109	108	106	105	104	103
140	5.862	121	120	119	118	117	116	115	113	112	111	110	109	108	106	105	104

# 104 METALLURGISTS AND CHEMISTS' HANDBOOK

## TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT.

Concluded

Pressure = 23.0 inches of mercury

		Depression of wet-bulb thermometer ( $t' - t'$ )																(t - t')				
Air temp., °F	Vapor press., in.	83	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
80	1.022	1	-11																			
81	1.056	6	-3	-21																		
82	1.091	11	+3	-9	-41																	
83	1.127	14	8	-1	-17																	
84	1.163	23	12	+5	-6	-20																
85	1.201	21	16	9	+1	-13																
86	1.241	23	19	13	0	-4	-23															
87	1.281	26	22	17	11	+3	-10	-54														
88	1.322	28	24	20	15	8	-1	-18														
89	1.364	30	27	23	18	12	+5	-7	-34													
90	1.408	32	29	25	21	16	10	+1	-14													
91	1.453	34	31	28	24	20	14	-7	-3	-25												
92	1.499	36	33	30	27	23	18	11	+3	-9	-59											
93	1.546	39	36	32	29	25	21	15	9	-1	-17											
94	1.595	41	38	35	31	28	24	19	13	+6	-5	-32										
95	1.645	42	40	37	33	30	26	22	17	11	+2	-12										
96	1.696	44	42	39	36	32	29	25	20	15	8	-2										
97	1.749	46	44	41	38	34	31	28	23	19	13	+5	-7	-41								
98	1.803	48	45	43	40	37	33	30	26	22	17	10	+1	-15								
99	1.859	50	47	45	42	39	36	32	29	25	21	14	7	-3	-28							
100	1.916	51	49	46	44	41	38	35	31	28	24	19	12	+4	-9							
101	1.975	53	51	48	46	43	40	37	34	30	26	22	17	10	+0	-18						
102	2.035	54	52	50	48	45	42	39	36	32	29	25	20	14	+7	-5	-32					
103	2.097	56	54	52	49	47	44	41	38	35	31	28	23	18	12	+3	-11					
104	2.162	57	55	53	51	49	46	43	40	37	34	30	26	22	16	9	-1					
105	2.225	59	57	55	53	50	48	45	42	39	36	33	29	25	20	14	+6					
106	2.292	60	58	56	54	52	50	47	44	42	39	35	32	28	24	18	12					
107	2.360	62	60	59	57	55	53	51	49	46	44	41	38	34	31	27	22	16				
108	2.431	63	61	59	57	55	53	51	48	46	43	40	37	33	29	25	20	18				
109	2.503	65	63	61	59	57	55	53	50	48	45	42	39	36	32	28	24	20				
110	2.576	66	64	62	60	58	56	54	52	50	47	44	41	38	34	31	27	24				
111	2.652	67	66	64	62	60	58	56	54	51	49	46	43	40	37	33	30	26				
112	2.730	69	67	65	63	62	60	57	55	53	51	48	46	43	40	36	32	30				
113	2.810	70	68	67	65	63	61	59	57	55	52	50	48	45	42	38	35	32				
114	2.891	71	70	68	66	64	63	61	59	56	54	52	49	47	44	41	38	35				
115	2.975	73	71	69	68	66	64	62	60	58	56	54	51	49	46	43	40	38				
116	3.061	74	72	71	69	67	66	64	62	60	58	55	53	50	48	45	42	40				
117	3.148	75	74	72	70	69	67	65	63	61	59	57	55	52	50	47	44	42				
118	3.239	77	75	73	72	70	68	67	65	63	61	59	57	54	52	49	47	45				
119	3.331	78	76	75	73	71	70	68	66	64	62	60	58	56	54	51	49	47				
120	3.425	79	78	76	74	73	71	69	68	66	64	62	60	58	55	53	50	48				
121	3.522	80	79	77	76	74	72	71	69	67	65	63	61	59	57	55	52	50				
122	3.621	82	80	79	77	75	74	72	70	69	67	65	63	61	59	57	54	52				
123	3.723	83	81	80	78	77	75	74	72	70	68	66	64	63	61	59	57	55				
124	3.827	84	83	81	80	78	76	75	73	72	70	68	66	64	63	61	58	56				
125	3.933	85	84	82	81	79	78	76	74	73	71	69	68	66	64	62	60	58				
126	4.042	86	85	84	82	81	79	78	76	74	72	71	69	68	66	64	62	60				
127	4.154	88	86	85	83	82	80	79	77	76	74	72	70	69	67	65	63	61				
128	4.268	89	87	86	85	83	82	80	78	77	75	74	72	70	69	67	65	63				
129	4.385	90	89	87	86	84	83	81	80	78	77	75	74	72	70	68	66	64				
130	4.504	91	90	88	87	86	84	83	81	80	78	77	75	73	72	70	68	66				
131	4.627	92	91	90	88	87	85	84	82	81	79	78	76	75	73	71	69	68				
132	4.752	93	92	91	89	88	87	85	84	82	81	79	78	76	74	72	71	69				
133	4.880	95	93	92	91	89	88	86	85	83	82	80	79	77	76	74	72	71				
134	5.011	96	94	93	92	90	89	88	86	85	83	82	80	78	77	75	73	72				
135	5.145	97	96	94	93	92	90	89	87	86	84	83	81	80	78	76	75	73				
136	5.282	98	97	95	94	93	91	90	89	87	86	84	83	81	80	78	76	75				
137	5.422	99	98	97	95	94	93	91	90	88	87	85	84	82	81	79	78	76				
138	5.565	100	99	98	96	95	94	92	91	90	88	87	85	84	82	81	79	78				
139	5.712	101	100	99	98	96	95	94	92	91	89	88	86	85	83	82	80	79				
140	5.862	103	101	100	99	97	96	95	93	92	91	89	88	86	85	83	81	80				

# PHYSICAL CONSTANTS

105

## RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES Pressure = 30.0 inches of mercury

Air temp., $t$	Depression of wet-bulb thermometer ( $t - t'$ )																			
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0
-40	48																			
-39	48																			
-38	50																			
-37	53	2																		
-36	56	10																		
-35	59	15																		
-34	61	20																		
-33	63	24																		
-32	64	28																		
-31	66	32	0																	
-30	68	36	4																	
-29	70	41	9																	
-28	72	45	15																	
-27	74	48	19																	
-26	75	51	24	0																
-25	76	53	29	5																
-24	77	55	32	10																
-23	78	57	36	15																
-22	80	59	39	20	0															
-21	81	61	43	24	5															
-20	82	63	45	28	10															
-19	83	65	48	32	15															
-18	84	67	51	35	19	2														
-17	85	69	53	39	23	7														
-16	86	70	56	42	27	12														
-15	86	72	58	45	31	17	4													
-14	87	74	61	48	34	21	8													
-13	88	75	63	50	38	25	13	0												
-12	88	76	64	52	41	29	17	6												
-11	89	77	66	55	44	32	21	10												
-10	90	78	68	57	46	36	25	14	4											
-9	90	79	70	59	49	39	29	18	9											
-8	90	81	71	61	51	42	32	22	13	3										
-7	91	82	72	63	54	44	35	26	17	8										
-6	91	82	73	64	56	47	38	29	20	12	3									
-5	91	83	75	66	58	49	41	32	24	16	7									
-4	92	84	76	68	60	52	44	36	28	20	12	4								
-3	92	85	77	69	61	54	46	39	31	23	16	8								
-2	92	85	78	71	63	56	49	42	34	27	19	12	5							
-1	93	86	79	72	65	58	51	44	37	30	23	16	10	3						
0	93	87	80	73	67	60	53	47	40	33	27	20	14	7	1					
+	93	87	81	75	68	62	56	49	43	36	30	24	18	11	5					
1	94	88	82	76	70	64	58	52	46	39	33	27	21	15	9	3				
2	94	88	82	77	71	65	59	54	48	42	36	30	25	19	13	7				
3	94	89	83	78	72	66	61	55	50	44	39	33	28	22	17	11	6			
4	95	89	84	78	73	68	63	57	52	46	41	36	31	25	20	15	10			
5	95	90	84	79	74	69	64	59	54	49	43	38	33	28	23	18	13	8		
6	95	90	85	80	75	70	65	60	55	51	46	41	36	31	26	21	17	12	7	2
7	95	90	86	81	76	71	67	62	57	53	48	43	38	34	29	24	20	15	11	6
8	95	91	86	82	77	72	68	63	59	55	50	46	41	36	32	27	23	18	14	10
9	96	91	87	82	78	73	69	65	60	56	52	47	43	39	34	30	26	22	17	13
10	96	91	87	83	79	74	70	66	62	58	53	49	45	41	37	33	28	25	20	16
11	96	92	88	84	80	75	71	67	63	59	55	51	47	43	39	35	31	27	23	19
12	96	92	88	84	80	76	73	69	65	61	57	53	49	45	41	38	34	30	26	23
13	96	92	89	85	81	77	74	70	66	62	59	55	51	48	44	40	37	33	29	26
14	96	93	89	86	82	78	75	71	67	64	60	57	53	50	46	42	39	35	32	29
15	96	93	90	86	82	79	76	72	69	65	62	58	55	51	48	45	41	38	34	31
16	97	93	90	86	83	80	77	73	70	66	63	60	57	53	50	47	43	40	37	34
17	97	93	90	87	84	80	77	74	71	68	65	61	58	55	52	49	45	42	39	36
18	97	93	90	87	84	81	78	75	72	69	66	63	60	56	53	50	47	44	41	38
19	97	94	90	87	84	81	78	75	72	69	66	63	60	56	53	50	47	44	41	38
20	97	94	91	88	85	82	79	76	73	70	67	64	61	58	55	52	49	46	43	40

## 106 METALLURGISTS AND CHEMISTS' HANDBOOK

## RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.

*Continued*

Pressure = 30.0 inches of mercury

Air temp., °F.	Depression of wet-bulb thermometer, (t - t')															
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
20	92	85	77	70	62	55	48	40	33	26	19	12	5			
21	92	85	78	71	63	56	49	42	35	28	21	15	8	1		
22	93	86	78	71	65	58	51	44	37	31	24	17	11	4		
23	93	86	79	72	66	59	52	46	39	33	26	20	14	7	1	
24	93	87	80	73	67	60	54	47	41	35	29	22	16	10	4	
25	94	87	81	74	68	62	55	49	43	37	31	25	19	13	7	
26	94	87	81	75	69	63	57	51	45	39	33	27	21	16	10	
27	94	88	82	76	70	64	58	52	47	41	35	29	24	18	13	
28	94	88	82	76	71	65	59	54	48	43	37	32	26	21	15	
29	94	88	83	77	72	66	60	55	50	44	39	34	28	23	18	
30	94	89	83	78	73	67	62	56	51	46	41	36	31	26	21	
31	94	89	84	78	73	68	63	58	52	47	42	37	33	28	23	
32	95	89	84	79	74	69	64	59	54	49	44	39	35	30	25	
33	95	90	85	80	75	70	65	60	56	51	46	41	37	32	27	
34	95	90	86	81	76	71	66	62	57	52	48	43	38	34	29	
35	95	91	86	81	77	72	67	63	58	54	49	45	40	36	32	
36	95	91	86	82	77	73	68	64	60	55	51	46	42	38	34	
37	95	91	87	83	78	74	69	65	61	57	53	48	44	40	36	
38	96	91	87	83	79	75	70	66	62	58	54	50	46	42	37	
39	96	92	87	83	79	75	71	67	63	59	55	51	47	43	39	
40	96	92	87	83	79	75	71	68	64	60	56	52	48	45	41	
41	96	92	88	84	80	76	72	69	65	61	57	54	50	46	42	
42	96	92	88	85	81	77	73	69	65	62	58	55	51	47	44	
43	96	92	88	85	81	77	73	70	66	63	59	55	52	48	45	
44	96	93	89	85	81	78	74	71	67	63	60	56	53	49	46	
45	96	93	89	86	82	78	74	71	67	64	61	57	54	51	47	
46	96	93	89	86	82	79	75	72	68	65	61	58	55	52	48	
47	96	93	89	86	82	79	75	72	69	66	62	59	56	53	49	
48	96	93	90	86	83	79	76	73	69	66	63	60	57	54	51	
49	96	93	90	86	83	80	76	73	70	67	64	61	57	54	51	
50	96	93	90	87	83	80	77	74	71	67	64	61	58	55	52	
51	97	94	90	87	84	81	78	75	72	69	66	63	60	57	54	
52	97	94	90	87	84	81	78	75	72	69	66	63	60	57	54	
53	97	94	90	87	84	81	78	75	72	69	66	63	61	58	55	
54	97	94	91	88	85	82	79	76	73	70	67	64	61	59	56	
55	97	94	91	88	85	82	79	76	73	70	68	65	62	59	57	
56	97	94	91	88	85	82	79	76	73	71	68	65	63	60	57	
57	97	94	91	88	85	82	80	77	74	71	69	66	63	61	58	
58	97	94	91	88	85	83	80	77	74	72	69	66	64	61	58	
59	97	94	91	89	86	83	80	78	75	72	70	67	65	62	59	
60	97	94	91	89	86	83	81	78	75	73	70	68	65	63	60	
61	97	94	92	89	86	84	81	78	76	73	71	68	65	63	61	
62	97	94	92	89	86	84	81	79	76	74	71	69	66	64	61	
63	97	95	92	89	87	84	82	79	77	74	71	69	67	65	63	
64	97	95	92	90	87	84	82	79	77	74	72	70	67	65	63	
65	97	95	92	90	87	85	82	80	77	75	72	70	68	66	64	
66	97	95	92	90	87	85	82	80	78	75	73	71	68	66	64	
67	97	95	92	90	87	85	83	80	78	75	73	71	69	66	64	
68	97	95	92	90	88	85	83	80	78	76	74	71	69	67	65	
69	97	95	93	90	88	85	83	81	79	76	74	72	70	67	65	
70	98	95	93	90	88	86	83	81	79	77	74	72	70	68	66	
71	98	95	93	90	88	86	84	81	79	77	75	72	70	68	66	
72	98	95	93	91	88	86	84	82	79	77	75	73	71	69	67	
73	98	95	93	91	88	86	84	82	80	78	75	73	71	69	67	
74	98	95	93	91	89	86	84	82	80	78	76	74	71	69	67	
75	98	96	93	91	89	86	84	82	80	78	76	74	72	70	68	
76	98	96	93	91	89	87	84	82	80	78	76	74	72	70	68	
77	98	96	93	91	89	87	85	83	81	79	77	74	72	71	69	
78	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	
79	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	
80	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
81	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
82	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
83	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
84	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
85	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
86	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
87	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
88	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
89	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
90	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
91	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
92	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
93	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
94	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
95	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
96	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
97	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
98	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
99	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	
100	98	96	94	91	89	87	85	83	81	79	77	75	73	71	69	

# PHYSICAL CONSTANTS

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RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.

Continued

Pressure = 30.0 inches of mercury

Air temp., $t$	Depression of wet-bulb thermometer ( $t - t'$ )															
	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5
35	2															
36	5	1														
37	7	3														
38	10	6														
39	12	8	2	1												
40	15	11	7	4	0											
41	17	13	10	6	3											
42	19	16	12	9	5	2										
43	21	18	14	11	8	4	1									
44	23	20	16	13	10	7	4	0								
45	25	22	18	15	12	9	6	3								
46	26	23	20	17	14	11	8	5	2							
47	28	25	22	19	16	13	10	7	5	2						
48	29	26	23	21	18	15	12	9	7	4	1					
49	31	28	25	22	19	17	14	11	9	6	3	1				
50	32	29	27	24	21	18	16	13	10	8	5	3	0			
51	34	31	28	26	23	20	17	15	12	9	7	4	2	1		
52	35	32	29	27	24	22	19	17	14	11	9	6	4	3	1	
53	36	33	31	28	26	23	20	18	16	13	10	8	6	5	3	1
54	37	35	32	29	27	24	22	20	17	15	12	10	8	7	5	3
55	38	36	33	31	28	26	23	21	19	16	14	12	10	9	7	5
56	39	37	34	32	30	27	25	22	20	18	16	13	11	9	7	5
57	40	38	35	33	31	28	26	24	22	19	17	15	13	10	8	6
58	41	39	37	34	32	30	27	25	23	21	18	14	14	12	10	8
59	42	40	38	35	33	31	29	26	24	22	20	18	16	13	11	9
60	43	41	39	37	34	32	30	28	26	23	21	19	17	15	13	11
61	44	42	40	38	35	33	31	29	27	25	22	20	18	16	14	12
62	45	43	41	39	36	34	32	30	28	26	24	22	20	18	16	14
63	46	44	42	40	37	35	33	31	29	27	25	23	21	19	17	15
64	47	45	43	41	38	36	34	32	30	28	26	24	22	20	18	17
65	48	46	44	41	39	37	35	33	31	29	27	25	24	22	20	18
66	48	46	44	42	40	38	36	34	32	30	29	27	25	23	21	19
67	49	47	45	43	41	39	37	35	33	31	30	28	26	24	22	20
68	50	48	46	44	42	40	38	36	34	32	31	29	27	25	23	21
69	51	49	47	45	43	41	39	37	35	33	32	30	28	26	24	23
70	51	49	48	46	44	42	40	38	36	34	33	31	29	27	25	24
71	52	50	48	46	45	43	41	39	37	35	33	32	30	28	27	25
72	53	51	49	47	45	43	42	40	38	36	34	33	31	29	28	26
73	53	51	50	48	46	44	42	40	39	37	35	34	32	30	29	27
74	54	52	50	48	47	45	43	41	39	38	36	34	33	31	30	28
75	54	53	51	49	47	45	44	42	40	39	37	35	34	32	30	29
76	55	53	51	50	48	46	44	43	41	39	38	36	34	33	31	30
77	56	54	52	50	48	47	45	43	42	40	39	37	35	34	32	31
78	56	54	53	51	49	47	46	44	43	41	39	38	36	34	33	31
79	57	55	53	51	50	48	46	45	43	42	40	38	37	35	34	32
80	57	55	54	52	50	49	47	45	44	42	41	39	38	36	35	33

# 108 METALLURGISTS AND CHEMISTS' HANDBOOK

## RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES. *Continued*

Pressure = 30.0 inches of mercury

		Depression of wet-bulb thermometers ( $t - t'$ )															
		21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	
61	1																
62	2																
63	4	1		0													
64	6	4		2	0												
65	7	5		4	2	0											
66	8	7		5	3	2											
67	10	8		7	5	3											
68	11	10		8	6	5	3	1									
69	13	11		9	8	6	5	3									
70	14	12		11	9	8	6	4	1								
71	15	13	12	10	9	7	6	4	3								
72	16	15	13	12	10	9	7	6	4	3							
73	17	16	14	13	11	10	8	7	5	4	3						
74	18	17	15	14	13	11	10	8	7	5	4	3					
75	20	18	17	15	14	12	11	9	8	7	5	4	3				
76	21	19	18	16	15	13	12	11	9	8	6	5	4	3			
77	22	20	19	17	16	14	13	12	10	9	8	6	5	4	3		
78	23	21	20	18	17	16	14	13	11	10	9	8	6	5	4		
79	23	22	21	19	18	17	15	14	13	11	10	9	7	6	5		
80	24	23	22	20	19	18	16	15	14	12	11	10	9	7	6	5	

Air temp., $t$	Depression of wet-bulb thermometer ( $t - t'$ )														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44
82	96	92	88	84	80	76	72	69	65	61	58	55	51	48	45
84	96	92	88	84	80	76	73	69	66	62	59	56	52	49	46
86	96	92	88	84	81	77	73	70	66	63	60	57	53	50	47
88	96	92	88	85	81	77	74	70	67	64	61	57	54	51	48
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49
92	96	92	89	85	82	78	75	72	68	65	62	59	56	53	50
94	96	93	89	85	82	79	75	72	69	66	63	60	57	54	51
96	96	93	89	86	82	79	76	73	69	66	63	61	58	55	52
98	96	93	89	86	83	79	76	73	70	67	64	61	58	56	53
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54
102	96	93	90	86	83	80	77	74	71	68	65	62	60	57	55
104	97	93	90	87	83	80	77	74	71	69	66	63	60	58	55
106	97	93	90	87	84	81	78	75	72	69	66	64	61	58	56
108	97	93	90	87	84	81	78	75	72	70	67	64	62	59	57
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57
112	97	94	90	87	84	81	79	76	73	70	68	65	63	60	58
114	97	94	91	88	85	82	79	76	74	71	68	66	63	61	58
116	97	94	91	88	85	82	79	76	74	71	69	66	64	61	59
118	97	94	91	88	85	82	79	77	74	72	69	67	64	62	59
120	97	94	91	88	85	83	80	77	74	72	69	67	65	62	60
122	97	94	91	88	85	83	80	77	75	72	70	67	65	63	60
124	97	94	91	88	85	83	80	78	75	73	70	68	65	63	61
126	97	94	91	88	86	83	80	78	75	73	70	68	66	64	61
128	97	94	91	89	86	83	81	78	76	73	71	68	66	64	62
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62
132	97	94	92	89	86	84	81	79	76	74	71	69	67	65	63
134	97	94	92	89	86	84	81	79	76	74	72	69	67	65	63
136	97	94	92	89	86	84	81	79	77	74	72	70	68	65	63
138	97	94	92	89	87	84	82	79	77	75	72	70	68	66	64
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64

RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.  
*Continued*

Pressure = 30.0 inches of mercury

t	Depression of wet-bulb thermometer (t - t')															
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
80	41	38	35	32	29	26	23	20	18	15	12	10	7	5	8	
82	42	39	36	33	30	28	25	22	20	17	14	12	10	7	5	
84	43	40	37	35	32	29	26	24	21	19	16	14	12	9	7	
86	44	42	39	36	33	31	28	26	23	21	18	16	14	11	9	
88	46	43	40	37	35	32	30	27	25	22	20	18	15	13	11	
90	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	
92	48	45	42	40	37	35	32	30	28	25	23	21	19	17	15	
94	49	46	43	41	38	36	33	31	29	27	24	22	20	18	16	
96	50	47	44	42	39	37	35	32	30	28	26	24	22	20	18	
98	50	48	45	43	40	38	36	34	32	29	27	25	23	21	19	
100	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	
102	52	49	47	45	42	40	38	36	34	32	30	28	26	24	22	
104	53	50	48	46	43	41	39	37	35	33	31	29	27	25	23	
106	53	51	49	46	44	42	40	38	36	34	32	30	28	26	24	
108	54	52	49	47	45	43	41	39	37	35	33	31	29	27	25	
110	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	
112	55	53	51	49	47	44	42	40	38	36	35	33	31	29	27	
114	56	54	52	49	47	45	43	41	39	37	35	34	32	30	28	
116	57	54	52	50	48	46	44	42	40	38	36	34	33	31	29	
118	57	55	53	51	49	47	45	43	41	39	37	35	34	32	30	
120	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31	
122	58	56	54	52	50	48	46	44	42	40	39	37	35	34	32	
124	59	57	54	52	50	48	47	45	43	41	39	38	36	34	32	
126	59	57	55	53	51	49	47	45	44	42	40	38	37	35	33	
128	60	58	56	54	52	50	48	46	44	42	41	39	37	36	34	
130	60	58	56	54	52	50	48	47	45	43	41	40	38	37	35	
132	61	58	56	55	53	51	49	47	45	44	42	40	39	37	36	
134	61	59	57	55	53	51	49	48	46	44	43	41	39	38	36	
136	61	59	57	55	54	52	50	48	46	45	43	41	40	38	37	
138	62	60	58	56	54	52	50	49	47	45	44	42	40	39	37	
140	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38	

or more, if necessary, until at least two successive readings of the wet bulb are found to agree very closely, thereby showing that it has reached its lowest temperature. A minute or more is generally required to secure the correct temperature.

When the air temperature is near the freezing point it often happens that the temperature of the wet bulb will fall several degrees below freezing point, but the water will still remain in the liquid state. No error results from this, provided the minimum temperature is reached. If, however, as frequently happens, the water suddenly freezes, a large amount of heat is liberated, and the temperature of the wet bulb immediately becomes 32°. In such cases it is necessary to continue the whirling until the ice-covered bulb has reached a minimum temperature.

The psychrometer will give fairly accurate indications, even in the sunshine, yet observations so made are not without some error, and where greater accuracy is desired, the psychrometer should be whirled in the shade.

[While the above is true for refined observations, such as were necessary in PROFESSOR MARVIN's work, yet for practical work I have found that a wet- and a dry-bulb thermometer, simply mounted on a board and placed in a good draft, would give accurate enough results for technical data. In this case the cloth wrapper of the wet-bulb thermometer went down into a cup of water, so that it was always wet and hence always ready for an observation. See also p. 115.—EDITOR.]

## 110 METALLURGISTS AND CHEMISTS' HANDBOOK

## RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.

*Continued*

Pressure = 30.0 inches of mercury

Air temp., $t$	Depression of wet-bulb thermometer ( $t - t'$ )														
	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
80	0														
82	2														
84	5	0													
86	7	3													
88	9	5	1												
90	11	7	3												
92	13	9	5	1											
94	14	12	10	7	3										
96	16	14	12	10	8	3									
98	17	15	14	12	10	8	3								
100	19	17	15	13	12	10	8	3							
102	20	18	16	15	13	11	10	8	3						
104	21	20	18	16	14	13	11	10	8	3					
106	23	21	19	17	16	14	13	11	10	8	3				
108	24	22	20	19	17	16	14	12	11	10	8	3			
110	25	23	21	20	18	17	15	14	12	11	10	8	3		
112	26	24	23	21	19	18	16	15	14	12	11	9	8	3	
114	27	25	24	22	20	19	18	16	15	13	12	11	9	8	3
116	28	26	25	23	22	20	19	17	16	14	13	12	11	9	8
118	29	27	25	24	23	21	20	18	17	16	14	13	12	11	9
120	29	28	26	25	23	22	21	19	18	17	15	14	13	12	10
122	30	29	27	26	24	23	22	20	19	18	16	15	14	13	11
124	31	30	28	27	25	24	22	21	20	18	17	16	15	14	12
126	32	30	29	27	26	25	23	22	21	19	18	17	16	15	13
128	33	31	30	28	27	25	24	23	22	20	19	18	17	16	14
130	33	32	30	29	28	26	25	24	22	21	20	19	18	16	15
132	34	33	31	30	28	27	26	24	23	22	21	20	18	17	16
134	35	33	32	30	29	28	26	25	24	23	21	20	19	18	17
136	35	34	33	31	30	28	27	26	25	23	22	21	20	19	18
138	36	35	33	32	30	29	28	27	25	24	23	22	21	20	19
140	37	35	34	32	31	30	29	27	26	25	24	23	21	20	19

$t$	Depression of wet-bulb thermometer ( $t - t'$ )														
	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
106	0														
108	2	0													
110	3	2	1												
112	4	3	2	1											
114	6	5	3	2	1										
116	7	6	5	4	2	1	0								
118	8	7	6	5	4	3		1							
120	9	8	7	6	5	4	3	2	1						
122	10	9	8	7	6	5	4	3	2	1	0				
124	11	10	9	8	7	6	5	4	3	2	1	0			
126	12	11	10	9	8	7	6	5	4	3	2	1	0		
128	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
130	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
132	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
134	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
136	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3
138	17	16	15	14	14	13	12	11	10	9	8	7	6	5	4
140	18	17	16	15	14	13	12	12	11	10	9	8	7	6	5



# PHYSICAL CONSTANTS

111

RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.

Continued

Pressure = 23.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer (t - t')																		
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8
-38	62	25																	
-37	64	28																	
-36	66	31																	
-35	68	35	4																
-34	70	39	9																
-33	72	42	14																
-32	73	45	18																
-31	74	48	22																
-30	76	51	26	1															
-29	77	54	30	6															
-28	79	57	34	12															
-27	80	59	37	18															
-26	81	62	40	22	2														
-25	82	64	44	26	8														
-24	82	65	47	30	13														
-23	83	66	50	34	18	0													
-22	84	68	53	37	22	5													
-21	85	70	55	40	26	10													
-20	86	71	57	44	30	15	2												
-19	86	73	59	47	34	20	6												
-18	87	74	62	50	37	24	11												
-17	88	75	63	52	40	27	16	3											
-16	89	77	65	54	43	31	20	8											
-15	89	78	67	57	46	35	24	13	2										
-14	90	79	69	59	48	38	28	17	7										
-13	90	80	71	61	51	41	31	22	12	2									
-12	90	81	72	63	53	44	35	26	16	7									
-11	91	82	73	64	56	47	38	29	20	11	2								
-10	92	83	75	66	58	50	41	32	24	16	7								
-9	92	84	76	68	60	52	44	36	28	20	12	4							
-8	92	85	77	69	62	54	46	38	31	23	16	8	0						
-7	93	85	78	70	63	56	49	41	34	27	20	12	5	3					
-6	93	86	79	72	65	58	51	44	37	30	23	16	9	7	0				
-5	93	86	80	73	66	59	53	46	40	33	26	20	13	11	4				
-4	93	87	81	74	68	61	55	49	42	36	30	23	17	10	8				
-3	94	88	82	75	69	63	57	51	45	39	33	27	21	14	12				
-2	94	88	82	76	70	65	59	53	47	41	36	30	24	18	12	7			
-1	94	89	83	77	72	66	61	55	50	44	39	33	28	22	16	11	6		
0	95	89	84	79	73	68	62	57	52	47	41	36	31	26	20	15	10	5	
+1	95	90	85	80	74	69	64	59	54	49	44	39	34	29	24	19	14	9	4
+2	95	90	85	81	76	71	66	61	56	51	47	42	37	32	27	22	18	13	8
+3	95	91	86	81	77	72	67	63	58	53	49	44	40	35	30	26	21	17	12
+4	95	91	86	82	77	73	69	64	60	55	51	46	42	38	33	29	24	20	16
+5	96	91	87	82	78	74	70	65	61	57	53	48	44	40	36	31	27	23	19
+6	96	91	87	83	79	75	71	66	62	58	54	50	46	42	38	34	30	26	22
+7	96	92	88	84	80	76	72	68	64	60	56	52	48	44	40	36	32	29	25
+8	96	92	88	84	80	76	73	69	65	61	58	54	50	46	42	39	35	31	28
+9	96	92	89	85	81	77	74	70	66	63	59	55	52	48	44	41	37	34	30
+10	96	93	89	85	82	78	74	71	68	64	61	57	53	50	46	43	39	36	32
+11	96	93	89	86	82	79	75	72	69	65	62	58	55	52	48	45	41	38	35
+12	97	93	90	86	83	80	76	73	70	66	63	60	57	53	50	47	43	40	37
+13	97	93	90	87	84	81	77	74	71	68	64	61	58	55	52	49	46	42	39
+14	97	94	91	87	84	81	78	75	72	69	66	63	60	57	54	51	48	45	42
+15	97	94	91	88	85	82	79	76	73	70	67	64	61	58	55	52	50	47	44
+16	97	94	91	88	85	83	80	77	74	71	68	66	63	60	57	54	51	49	46
+17	97	94	92	89	86	83	81	78	75	72	69	67	64	61	59	56	53	50	48
+18	97	95	92	89	86	84	81	79	76	73	71	68	65	63	60	57	55	52	50
+19	97	95	92	89	87	84	82	79	77	74	71	69	66	64	61	59	56	54	51
+20	97	95	92	90	87	85	82	80	77	75	72	70	67	65	63	60	57	55	53

## 112 METALLURGISTS AND CHEMISTS' HANDBOOK

## RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.

Continued

Pressure = 30.0 inches of mercury

Air temp., $t$	Depression of wet-bulb thermometer ( $t - t'$ )																			
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
20	94	87	81	75	69	63	58	50	44	38	32	26	21	15	9	3				
21	94	87	81	75	69	63	57	52	46	40	34	29	23	17	12	6	1			
22	94	88	82	76	70	64	59	53	47	42	36	31	25	20	15	9	4			
23	94	88	82	77	71	65	60	54	49	43	38	33	28	22	17	12	7	2		
24	94	89	83	78	72	67	61	56	50	45	40	35	30	25	20	15	10	5		
25	95	89	84	78	73	68	62	57	52	47	42	37	32	27	22	17	12	8	3	
26	95	89	84	79	73	68	63	58	53	48	43	38	34	29	24	19	15	10	6	1
27	95	90	84	79	74	69	64	59	55	50	45	40	35	31	26	22	17	13	8	4
28	95	90	85	80	75	70	65	60	56	51	46	42	37	33	28	24	19	15	11	6
29	95	90	85	80	76	71	66	62	57	52	48	43	39	35	30	26	22	17	13	9
30	95	90	86	81	76	72	67	63	58	54	49	45	41	36	32	28	24	20	16	11
31	95	91	86	81	77	72	68	64	59	55	51	46	42	38	34	30	26	22	18	14
32	95	91	86	82	77	73	69	65	60	56	52	48	44	40	36	32	28	24	20	16
33	96	92	87	83	78	74	70	66	62	57	53	49	45	41	38	34	30	26	22	18
34	96	92	88	84	79	75	71	67	63	59	55	51	47	43	39	35	32	28	24	21
35	96	92	88	84	80	76	72	68	64	60	56	52	49	45	41	37	34	30	26	23
36	96	92	88	84	80	77	73	69	65	61	58	54	50	46	43	39	35	32	28	25
37	96	93	89	85	81	78	74	70	66	63	59	55	52	48	44	41	37	34	30	27
38	96	93	89	85	81	78	74	71	67	64	60	57	53	49	46	42	39	36	32	29
39	96	93	89	85	81	78	75	71	68	65	61	57	54	51	48	44	41	37	34	31
40	96	93	89	85	82	79	75	72	68	65	62	58	55	52	49	45	42	39	36	32
41	96	93	89	86	82	79	76	72	69	66	62	59	56	53	50	47	44	41	37	34
42	96	93	89	86	83	80	76	73	70	67	63	60	57	54	51	48	45	42	39	36
43	96	93	90	87	83	80	77	73	70	67	64	61	58	55	52	49	46	43	40	37
44	97	94	90	87	83	80	77	74	71	68	65	62	59	56	53	50	47	44	41	39
45	97	94	90	87	84	81	78	74	71	68	65	62	60	57	54	51	48	45	42	40
46	97	94	90	87	84	81	78	75	72	69	66	63	60	57	55	52	49	46	44	41
47	97	94	90	87	84	81	78	75	72	70	67	64	61	58	55	52	49	47	45	42
48	97	94	91	88	85	82	79	76	73	70	67	65	62	59	56	54	51	48	46	43
49	97	94	91	88	85	82	79	76	73	71	68	65	62	60	57	54	52	49	47	44
50	97	94	91	88	85	82	79	77	74	71	68	66	63	60	57	55	52	50	48	45
51	97	94	91	88	86	83	80	77	75	72	69	66	64	61	58	56	53	51	49	46
52	97	94	91	89	86	83	80	78	75	72	70	67	64	61	59	57	54	52	49	47
53	97	94	91	89	86	83	80	78	75	72	70	67	65	62	60	57	55	52	50	48
54	97	94	92	89	86	83	81	78	76	73	70	68	65	63	60	58	56	53	51	48
55	97	95	92	89	86	83	81	78	76	73	71	69	66	63	61	59	56	54	52	49
56	97	95	92	89	87	84	81	79	76	74	71	69	67	64	62	59	57	55	53	51
57	97	95	92	89	87	84	82	79	77	74	72	69	67	65	62	60	57	55	53	51
58	97	95	92	89	87	84	82	79	77	74	72	70	67	65	63	61	58	56	54	52
59	97	95	92	90	87	85	82	80	77	75	73	70	68	65	63	61	59	57	55	53
60	97	95	92	90	87	85	82	80	78	75	73	71	68	66	64	62	59	57	55	53
61	97	95	92	90	88	85	83	80	78	76	73	71	69	67	65	63	61	59	57	55
62	97	95	92	90	88	85	83	81	78	76	74	72	69	67	65	63	61	59	56	54
63	97	95	93	90	88	85	83	81	79	76	74	72	70	67	65	63	61	59	57	55
64	97	95	93	90	88	86	83	81	79	77	74	72	70	68	66	64	62	60	58	56
65	98	95	93	91	88	86	84	81	79	77	75	73	71	69	68	66	64	62	60	58
66	98	95	93	91	88	86	84	82	79	77	75	73	71	69	67	65	63	61	59	57
67	98	95	93	91	89	86	84	82	80	77	75	73	71	69	67	65	63	61	59	57
68	98	95	93	91	89	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58
69	98	96	93	91	89	87	85	83	80	78	76	74	72	70	68	66	64	62	60	58
70	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	63	61	59
71	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	63	61	59
72	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	64	62	60
73	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	68	66	64	62	60
74	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	66	64	63	61
75	98	96	94	92	90	88	86	84	82	80	78	76	74	72	70	68	66	65	63	61
76	98	96	94	92	90	88	86	84	82	80	78	76	74	72	71	69	67	66	64	62
77	98	96	94	92	90	88	86	84	82	80	78	76	74	72	71	69	67	66	64	62
78	98	96	94	92	90	88	86	84	82	80	78	76	74	72	71	69	68	66	64	62
79	98	96	94	92	90	88	86	84	82	80	78	77	75	73	71	70	68	66	65	63
80	98	96	94	92	90	88	86	84	82	80	79	77	75	73	72	70	68	67	65	63

RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.

*Continued*

Pressure = 23.0 inches of mercury

Air temp., $t$		Depression of wet-bulb thermometer ( $t - t'$ )																				
		11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0
29	1																					
30	4																					
31	6	2																				
32	9	5																				
33	11	7	1																			
34	13	10	6	3																		
35	16	12	9	5																		
36	18	15	11	8																		
37	20	17	13	10	7	4	0															
38	22	19	16	12	9	6	3															
39	24	21	18	15	12	8	5	2														
40	26	23	20	17	14	11	8	5	2													
41	28	25	22	19	16	13	10	7	4	1												
42	30	27	24	21	18	15	12	9	6	3	0											
43	31	28	26	23	20	17	14	11	8	6	3	0										
44	33	30	27	25	22	19	16	13	11	8	5	3	0									
45	34	31	28	26	24	21	18	15	13	10	7	5	2									
46	35	33	30	27	25	22	20	17	15	12	9	7	4	2								
47	37	34	31	29	26	24	21	19	17	14	11	9	6	4	2							
48	38	35	32	30	28	25	23	21	18	16	13	11	9	6	4	2						
49	39	37	34	31	29	27	24	22	20	17	15	13	10	8	6	3	1					
50	40	38	35	33	30	28	26	23	21	19	17	14	12	10	8	6	3	1				
51	41	39	36	34	32	29	27	25	23	20	18	16	14	12	9	7	5	3	1			
52	42	40	37	35	33	31	28	26	24	22	20	17	15	13	11	9	7	5	3	1		
53	43	41	38	36	34	32	29	27	25	23	21	19	17	15	13	11	9	7	5	3	1	
54	44	42	39	37	35	33	31	29	26	24	22	20	18	16	14	12	10	8	6	4	2	
55	45	43	40	38	36	34	32	30	28	26	24	22	20	18	16	14	12	10	8	6	4	
56	46	44	41	39	37	35	33	31	29	27	25	23	21	19	17	15	13	11	9	7	6	
57	47	44	42	40	38	36	34	32	30	28	26	24	22	20	18	16	14	13	11	9	7	
58	48	45	43	41	39	37	35	33	31	29	27	25	23	21	20	18	16	14	12	10	9	
59	48	46	44	42	40	38	36	34	32	30	28	26	24	22	21	19	17	15	14	12	10	
60	49	47	45	43	41	39	37	35	33	31	29	27	26	24	22	20	18	16	15	13	11	
61	50	48	46	44	42	40	38	36	34	32	30	29	27	25	23	21	20	18	16	14	13	
62	50	48	46	45	43	41	39	37	35	33	31	30	28	26	24	23	21	19	17	16	14	
63	51	49	47	45	43	41	40	38	36	34	32	31	29	27	25	24	22	20	19	17	15	
64	52	50	48	46	44	42	40	39	37	35	33	32	30	28	26	25	23	21	20	18	16	
65	52	50	49	47	45	43	41	39	38	36	34	32	31	29	27	26	24	22	21	19	18	
66	53	51	49	47	46	44	42	40	38	37	35	33	32	30	28	27	25	24	22	20	19	
67	54	52	50	48	46	44	43	41	39	37	36	34	33	31	29	28	26	25	23	21	20	
68	54	52	50	49	47	45	44	42	40	38	37	35	33	32	30	29	27	25	24	22	21	
69	55	53	51	49	48	46	44	42	41	39	37	36	34	33	31	30	28	26	25	23	22	
70	55	53	52	50	48	47	45	43	42	40	38	37	35	33	32	30	29	27	26	24	23	
71	56	54	52	51	49	47	46	44	42	41	39	37	36	34	33	31	30	28	27	25	24	
72	56	55	53	51	50	48	46	45	43	41	40	38	37	35	34	32	31	29	28	26	25	
73	57	55	53	52	50	48	47	45	44	42	40	39	37	36	34	33	31	30	29	27	26	
74	57	56	54	52	51	49	47	46	44	43	41	39	38	37	35	34	32	31	29	28	27	
75	58	56	55	53	51	50	48	46	45	43	42	40	39	37	36	34	33	32	30	29	27	
76	58	57	55	53	52	50	49	47	45	44	42	41	39	38	37	35	34	32	31	29	28	
77	59	57	56	54	52	51	49	48	46	44	43	41	40	39	37	36	34	33	32	30	29	
78	59	57	56	54	53	51	50	48	47	45	44	42	41	39	38	36	35	34	32	31	29	
79	60	58	56	55	53	52	50	49	47	46	44	43	41	40	39	37	36	34	33	32	30	
80	60	58	57	55	54	52	51	49	48	46	45	43	42	41	39	38	37	35	34	33	31	

## 114 METALLURGISTS AND CHEMISTS' HANDBOOK

## RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.

Continued

Pressure = 23.0 inches of mercury

$t$	$(t - t')$															
	22	23	24	25	26	27	28	29	30	31	32	33	34			
60	8	5	1													
61	9	6	3													
62	11	8	4	1												
63	12	9	6	3												
64	13	10	7	4	1											
65	15	12	9	6	3											
66	16	13	10	7	4	1										
67	17	14	11	8	5	3										
68	18	15	12	9	7	4	1									
69	19	16	13	11	8	5	3	0								
70	20	17	14	12	9	6	4	1								
71	21	18	15	13	10	8	5	3	0							
72	22	19	16	14	11	9	6	4	1							
73	23	20	17	15	12	10	7	5	3	0						
74	24	21	18	16	13	11	9	6	4	2						
75	25	22	19	17	14	12	10	7	5	3	1					
76	25	23	20	18	15	13	11	8	6	4	2					
77	26	24	21	19	16	14	12	9	7	5	3	1				
78	27	25	22	20	17	15	13	10	8	6	4	2				
79	28	26	23	21	18	16	14	11	9	7	5	3	1			
80	29	26	24	21	19	17	15	12	10	8	6	4	2			

Air temp., $t$	Depression of wet-bulb thermometer $(t - t')$															
	1	2	3	4	5	6	7	8	9	10	11	12	12	14	15	16
80	96	92	88	84	80	77	73	70	67	63	60	57	54	51	48	45
82	96	92	88	85	81	77	74	71	67	64	61	58	55	52	49	46
84	96	92	89	85	81	78	74	71	68	65	61	58	55	53	50	47
86	96	93	89	85	81	78	75	71	68	65	62	59	56	53	50	48
88	96	93	89	85	82	79	75	72	69	66	63	60	57	54	51	49
90	96	93	89	86	82	79	76	73	69	66	63	61	58	55	52	50
92	96	93	89	86	84	79	76	73	70	67	64	61	58	56	53	51
94	96	93	89	86	83	80	76	73	70	67	65	62	59	56	54	51
96	96	93	90	86	83	80	77	74	71	68	65	62	60	57	55	52
98	97	93	90	87	83	80	77	74	71	68	66	63	60	58	55	53
100	97	93	90	87	84	80	77	75	72	69	66	64	61	58	56	53
102	97	93	90	87	84	81	78	75	72	69	67	64	61	59	57	54
104	97	93	90	87	84	81	78	75	72	70	67	65	62	59	57	55
106	97	94	90	87	84	81	78	76	73	70	68	65	62	60	58	55
108	97	94	90	87	84	82	79	76	73	71	68	65	63	61	58	56
110	97	94	91	88	85	82	79	76	74	71	68	65	63	61	59	57
112	97	94	91	88	85	82	79	77	74	71	68	66	63	61	59	57
114	97	94	91	88	85	82	80	77	74	72	69	67	64	62	60	58
116	97	94	91	88	85	82	80	77	75	72	70	67	65	62	60	58
118	97	94	91	88	85	83	80	77	75	72	70	67	65	63	61	58
120	97	94	91	88	85	83	80	77	75	73	70	68	65	63	61	59
122	97	94	91	89	86	83	80	78	75	73	71	68	66	64	62	59
124	97	94	91	89	86	83	81	78	76	73	71	68	66	64	62	60
126	97	94	91	89	86	83	81	78	76	74	71	69	67	65	62	60
128	97	94	91	89	86	84	81	79	76	74	72	69	67	65	63	61
130	97	94	92	89	86	84	81	79	76	74	72	70	67	65	63	61
132	97	94	92	89	86	84	81	79	77	74	72	70	68	66	64	62
134	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62
136	97	95	92	89	87	84	82	79	77	75	73	71	69	66	64	62
138	97	95	92	89	87	84	82	80	77	75	73	71	69	66	64	62
140	97	95	92	90	87	85	82	80	78	75	73	71	69	67	65	63

## RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.

*Continued*

Pressure = 23.0 inches of mercury

<i>t</i>	Depression of wet-bulb thermometer ( <i>t</i> - <i>t'</i> )															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
80	42	39	37	34	31	29	26	24	21	19	17	15	12	10	8	6
82	43	40	38	35	33	30	28	25	23	21	19	16	14	12	10	8
84	44	42	39	36	34	31	29	27	24	22	20	18	16	14	12	10
86	45	43	40	38	35	33	30	28	26	24	22	20	17	15	13	12
88	46	44	41	39	36	34	32	29	27	25	23	21	19	17	15	13
90	47	45	42	40	37	35	33	31	28	26	24	22	20	18	17	15
92	48	46	43	41	38	36	34	32	30	28	26	24	22	20	18	16
94	49	46	44	42	39	37	35	33	31	29	27	25	23	21	19	18
96	50	47	45	43	40	38	36	34	32	30	28	26	24	22	21	19
98	50	48	46	43	41	39	37	35	33	31	29	27	25	24	22	20
100	51	49	46	44	42	40	38	36	34	32	30	28	26	25	23	21
102	52	50	47	45	43	41	39	37	35	33	31	29	27	26	24	22
104	52	50	48	46	44	42	40	38	36	34	32	30	28	27	25	23
106	53	51	49	47	44	42	40	38	37	35	33	31	29	28	26	24
108	54	51	49	47	45	43	41	39	37	36	34	32	30	29	27	25
110	54	52	50	48	46	44	42	40	38	36	35	33	31	30	28	26
112	55	53	51	48	46	45	43	41	39	37	35	34	32	30	29	27
114	55	53	51	49	47	45	43	41	40	38	36	34	33	31	30	28
116	56	54	52	50	48	46	44	42	40	39	37	35	34	32	30	29
118	56	54	52	50	48	46	45	43	41	39	38	36	34	33	31	30
120	57	55	53	51	49	47	45	43	42	40	38	37	35	33	32	30
122	57	55	53	51	49	48	46	44	42	41	39	37	36	34	33	31
124	58	56	54	52	50	48	46	45	43	41	39	38	36	35	33	32
126	58	56	54	52	50	49	47	45	43	42	40	39	37	35	34	33
128	59	57	55	53	51	49	47	46	44	42	41	39	38	36	35	33
130	59	57	55	53	51	50	48	46	45	43	41	40	38	37	35	34
132	59	57	56	54	52	50	48	47	45	43	42	40	39	37	36	34
134	60	58	56	54	52	51	49	47	46	44	42	41	39	38	36	35
136	60	58	56	55	53	51	49	48	46	44	43	41	40	38	37	36
138	61	59	57	55	53	51	50	48	46	45	43	42	40	39	37	36
140	61	59	57	55	54	52	50	49	47	45	44	42	41	39	38	37

In *Coal Age* there appeared the following simple formula for calculating humidities of the air from the ordinary hygrometer readings: this is:

$$100 - H = \frac{460}{d} (d - w)^{0.84}$$

in which *d* and *w* are the dry- and wet-bulb readings (Fahrenheit) and *H* is the percentage humidity. This formula requires logarithms, and is for sea level. A simpler one can be devised to suit the underground conditions of the mines, where neither the temperature nor the humidity varies much.

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## RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.

*Continued*

Pressure = 23.0 inches of mercury

Air temp., <i>t</i>	Depression of wet-bulb thermometer ( <i>t</i> - <i>t'</i> )															
	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
80	4	2	0													
82	6	4	2	0												
84	8	6	4	2	1											
86	11	8	6	4	2	1										
88	11	10	8	6	4	3	1									
90	13	11	9	8	6	4	3	1								
92	14	13	11	9	8	6	5	3	2	0						
94	16	14	12	11	9	8	6	5	3	2	0					
96	17	15	14	12	11	9	8	6	5	3	2	1	0			
98	18	17	15	14	12	11	9	8	6	5	4	2	1			
100	20	18	16	15	13	12	10	9	8	6	5	4	2	1		
102	21	19	18	16	15	13	12	10	9	8	6	5	4	3	1	0
104	22	20	19	17	16	14	13	12	10	9	8	6	5	4	3	2
106	23	21	20	18	17	16	14	13	11	10	9	8	7	5	4	3
108	24	22	21	19	18	17	15	14	12	11	10	9	8	7	5	4
110	25	23	22	20	19	18	16	15	14	12	11	10	9	8	7	6
112	26	24	23	21	20	19	17	16	15	14	12	11	10	9	8	7
114	27	25	24	22	21	20	18	17	16	15	13	12	11	10	9	8
116	27	26	25	23	22	20	19	18	17	15	14	13	12	11	10	9
118	28	27	25	24	23	21	20	19	18	16	15	14	13	12	11	10
120	29	28	26	25	23	22	21	20	18	17	16	15	14	13	12	11
122	30	28	27	26	24	23	22	21	19	18	17	16	15	14	13	12
124	30	29	28	26	25	24	22	21	20	19	18	17	16	15	14	13
126	31	30	28	27	26	25	23	22	21	20	19	18	16	15	14	13
128	32	30	29	28	26	25	24	23	22	20	19	18	17	16	15	14
130	32	31	30	28	27	26	25	23	22	21	20	19	18	17	16	15
132	33	32	30	29	28	27	25	24	23	22	21	20	19	18	17	16
134	34	32	31	30	29	27	26	25	24	23	21	20	19	18	17	16
136	34	33	32	30	29	28	27	25	24	23	22	21	20	19	18	17
138	35	33	32	31	30	28	27	26	25	24	23	22	21	20	19	18
140	35	34	33	31	30	29	28	27	26	24	23	22	21	20	19	18

The following formula is for 27 in. barometer, or about 3,000 ft. above sea-level (but 1,000 ft. more or less makes little difference) and holds true for all readings likely to occur in the mines.

$$100 - H = (d - w) \left( \frac{165 - d}{20} \right)$$

Thus, if  $d = 75$  and  $w = 73$ ,  $100 - H = 2 \times 4.5$ , and  $H = 91$  per cent., and if  $d = 95$  and  $w = 92$ ,  $100 - H = 3 \times 3.5$ ,  $H = 89.5$  per cent. These both agree very closely with the data in the Smithsonian tables; therefore the formula must be correct for all dry-bulb readings between  $75^{\circ}$  and  $95^{\circ}\text{F.}$ , especially since the wet-bulb cannot be read with sufficient accuracy to give  $H$  within  $\frac{1}{4}$  per cent.

TABLE XI.—PRESSURE OF AQUEOUS VAPOR FOR TEMPERATURE FROM 100° TO 445°F., IN INCHES OF MERCURY

Temp., °F.	0	1	2	3	4	5	6	7	8	9
100	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
110	1.916	1.975	2.035	2.097	2.160	2.225	2.292	2.360	2.431	2.503
120	2.576	2.652	2.730	2.810	2.891	2.975	3.061	3.148	3.239	3.331
130	3.425	3.522	3.621	3.723	3.827	3.933	4.042	4.154	4.268	4.385
140	4.504	4.627	4.752	4.880	5.011	5.145	5.282	5.422	5.565	5.712
150	5.862	6.015	6.171	6.331	6.495	6.662	6.832	7.006	7.184	7.366
160	7.552	7.742	7.936	8.133	8.335	8.541	8.752	8.966	9.186	9.409
170	9.637	9.870	10.108	10.350	10.597	10.850	11.107	11.369	11.636	11.909
180	12.187	12.470	12.759	13.054	13.354	13.660	13.972	14.289	14.613	14.943
190	15.279	15.621	15.970	16.325	16.687	17.055	17.430	17.812	18.202	18.598
200	19.001	19.412	19.830	20.255	20.688	21.129	21.578	22.034	22.499	22.972
210	23.45	23.94	24.44	24.95	25.46	25.99	26.52	27.06	27.62	28.18
220	28.75	29.33	29.92	30.52	31.13	31.75	32.38	33.02	33.67	34.33
230	35.01	35.69	36.38	37.08	37.79	38.52	39.26	40.01	40.77	41.55
240	42.34	43.14	43.94	44.76	45.59	46.44	47.31	48.19	49.08	49.98
250	50.89	51.82	52.76	53.72	54.69	55.67	56.67	57.68	58.71	59.76
260	60.82	61.89	62.98	64.08	65.20	66.33	67.48	68.66	69.85	71.04
270	72.26	73.50	74.75	76.02	77.31	78.61	79.93	81.27	82.63	84.01
280	85.41	86.82	88.25	89.70	91.18	92.67	94.18	95.70	97.25	98.82
290	100.41	102.03	103.66	105.32	106.99	108.69	110.41	112.15	113.91	115.69
300	117.50	119.33	121.18	123.05	124.94	126.86	128.81	130.78	132.78	134.80
310	136.8	138.9	141.0	143.1	145.2	147.4	149.6	151.8	154.1	156.4
320	158.7	161.0	162.3	165.7	168.1	170.6	173.0	175.5	178.0	180.5
330	183.1	185.8	188.4	191.1	193.8	196.5	199.3	202.1	204.9	207.7
340	210.6	213.5	216.4	219.4	222.4	225.4	228.5	231.6	234.7	237.9
350	241.1	244.3	247.6	250.9	254.2	257.6	261.1	264.5	268.0	271.5
360	275.1	278.7	282.3	285.9	289.6	293.3	297.1	300.9	304.8	308.7
370	312.6	316.5	320.5	324.6	328.7	332.8	336.9	341.2	345.4	349.7
380	354.1	358.4	362.8	367.3	371.8	376.4	380.9	385.5	390.2	394.9
390	399.7	404.5	409.3	414.1	419.1	424.1	429.1	434.1	439.2	444.4
400	449.7	454.9	460.1	465.5	470.9	476.4	481.9	487.4	493.0	498.7
410	504.4	510.1	515.9	521.7	527.6	533.6	539.5	545.6	551.7	557.9
420	564.1	570.3	576.6	582.9	589.3	595.7	602.3	608.9	615.5	622.1
430	628.8	635.6	642.5	649.4	656.3	663.3	670.4	677.5	684.7	691.9
440	699.2	706.6	714.0	721.4	728.9	736.5	744.2	751.9	759.6	767.4
450	775.3	783.2	791.3	799.3	807.4	815.5				

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## WEIGHT OF A CUBIC FOOT OF AQUEOUS VAPOR AT DIFFERENT TEMPERATURES AND SATURATIONS (IN GRAINS)

Temp., °F.	Percentage of saturation									
	10	20	30	40	50	60	70	80	90	100
	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.
—20	0.017	0.033	0.050	0.066	0.083	0.100	0.116	0.133	0.149	0.166
—19	0.017	0.035	0.052	0.070	0.087	0.104	0.122	0.139	0.157	0.174
—18	0.018	0.037	0.055	0.074	0.092	0.109	0.129	0.147	0.166	0.184
—17	0.020	0.039	0.059	0.078	0.098	0.118	0.137	0.157	0.176	0.196
—16	0.021	0.041	0.062	0.083	0.104	0.124	0.145	0.166	0.186	0.207
—15	0.022	0.044	0.065	0.087	0.109	0.131	0.153	0.174	0.196	0.218
—14	0.023	0.046	0.069	0.092	0.116	0.139	0.162	0.185	0.208	0.231
—13	0.024	0.049	0.073	0.097	0.122	0.146	0.170	0.194	0.219	0.243
—12	0.026	0.051	0.077	0.103	0.128	0.154	0.180	0.206	0.231	0.257
—11	0.027	0.054	0.081	0.108	0.135	0.162	0.189	0.216	0.243	0.270
—10	0.028	0.057	0.086	0.114	0.142	0.171	0.200	0.228	0.256	0.285
—9	0.030	0.060	0.090	0.120	0.150	0.180	0.210	0.240	0.270	0.300
—8	0.032	0.063	0.095	0.126	0.158	0.190	0.221	0.253	0.284	0.316
—7	0.033	0.066	0.100	0.133	0.166	0.199	0.232	0.266	0.299	0.332
—6	0.035	0.070	0.105	0.140	0.175	0.210	0.245	0.280	0.315	0.350
—5	0.037	0.074	0.111	0.148	0.185	0.222	0.259	0.296	0.333	0.370
—4	0.039	0.078	0.117	0.156	0.194	0.233	0.272	0.311	0.350	0.389
—3	0.041	0.082	0.123	0.164	0.206	0.247	0.288	0.329	0.370	0.411
—2	0.043	0.087	0.130	0.174	0.217	0.260	0.304	0.347	0.391	0.434
—1	0.046	0.091	0.137	0.183	0.228	0.274	0.320	0.366	0.411	0.457
0	0.048	0.096	0.144	0.192	0.240	0.289	0.337	0.385	0.433	0.481
1	0.050	0.101	0.152	0.202	0.252	0.303	0.354	0.404	0.454	0.505
2	0.053	0.106	0.159	0.212	0.264	0.317	0.370	0.423	0.476	0.529
3	0.055	0.111	0.166	0.222	0.277	0.332	0.388	0.443	0.499	0.554
4	0.058	0.116	0.175	0.233	0.291	0.349	0.407	0.466	0.524	0.582
5	0.061	0.122	0.183	0.244	0.305	0.366	0.427	0.488	0.549	0.610
6	0.064	0.128	0.192	0.256	0.320	0.383	0.447	0.511	0.575	0.639
7	0.067	0.134	0.201	0.268	0.336	0.403	0.470	0.537	0.604	0.671
8	0.070	0.141	0.211	0.282	0.352	0.422	0.493	0.563	0.634	0.704
9	0.074	0.148	0.222	0.296	0.370	0.443	0.517	0.591	0.665	0.739
10	0.078	0.155	0.233	0.310	0.388	0.466	0.543	0.621	0.698	0.776
11	0.082	0.163	0.245	0.326	0.408	0.490	0.571	0.653	0.734	0.816
12	0.086	0.171	0.257	0.342	0.428	0.514	0.599	0.685	0.770	0.856
13	0.090	0.180	0.269	0.359	0.449	0.539	0.629	0.718	0.808	0.898
14	0.094	0.188	0.282	0.376	0.470	0.565	0.659	0.753	0.847	0.941
15	0.099	0.197	0.296	0.394	0.493	0.592	0.690	0.789	0.887	0.986
16	0.103	0.206	0.310	0.413	0.516	0.619	0.722	0.826	0.929	1.032
17	0.108	0.216	0.324	0.432	0.540	0.648	0.756	0.864	0.972	1.080
18	0.113	0.226	0.338	0.451	0.564	0.677	0.790	0.902	1.015	1.128
19	0.118	0.236	0.354	0.472	0.590	0.709	0.827	0.945	1.063	1.181
20	0.124	0.247	0.370	0.494	0.618	0.741	0.864	0.988	1.112	1.235
21	0.129	0.259	0.388	0.518	0.647	0.776	0.906	1.035	1.165	1.294
22	0.136	0.271	0.406	0.542	0.678	0.813	0.948	1.084	1.220	1.355
23	0.142	0.284	0.425	0.567	0.709	0.851	0.993	1.134	1.276	1.418
24	0.148	0.297	0.445	0.593	0.742	0.890	1.038	1.186	1.335	1.483
25	0.155	0.310	0.465	0.620	0.776	0.931	1.086	1.241	1.396	1.551
26	0.162	0.325	0.487	0.649	0.812	0.974	1.136	1.298	1.461	1.623
27	0.170	0.339	0.509	0.679	0.848	1.018	1.188	1.358	1.527	1.697



WEIGHT OF A CUBIC FOOT OF AQUEOUS VAPOR AT DIFFERENT TEMPERATURES AND SATURATIONS (IN GRAINS). *Continued*

Temp., °F.	Percentage of saturation									
	10	20	30	40	50	60	70	80	90	100
28	Gr. 0.177	Gr. 0.355	Gr. 0.532	Gr. 0.709	Gr. 0.886	Gr. 1.064	Gr. 1.241	Gr. 1.418	Gr. 1.596	Gr. 1.773
29	0.185	0.371	0.556	0.741	0.926	1.112	1.297	1.482	1.668	1.853
30	0.194	0.387	0.580	0.774	0.968	1.161	1.354	1.548	1.742	1.935
31	0.202	0.404	0.607	0.809	1.011	1.213	1.415	1.618	1.820	2.022
32	0.211	0.422	0.634	0.845	1.056	1.268	1.479	1.690	1.902	2.113
33	0.219	0.439	0.658	0.878	1.097	1.316	1.536	1.755	1.975	2.194
34	0.228	0.456	0.684	0.912	1.140	1.367	1.595	1.823	2.051	2.279
35	0.237	0.473	0.710	0.946	1.183	1.420	1.656	1.893	2.129	2.366
36	0.246	0.491	0.737	0.983	1.228	1.474	1.720	1.966	2.211	2.457
37	0.255	0.510	0.765	1.020	1.275	1.530	1.785	2.040	2.295	2.550
38	0.265	0.529	0.794	1.058	1.323	1.588	1.852	2.117	2.381	2.646
39	0.275	0.549	0.824	1.098	1.373	1.648	1.922	2.197	2.471	2.746
40	0.285	0.570	0.855	1.140	1.424	1.709	1.994	2.279	2.564	2.849
41	0.296	0.591	0.886	1.182	1.478	1.773	2.068	2.364	2.660	2.955
42	0.306	0.613	0.919	1.226	1.532	1.838	2.145	2.451	2.758	3.064
43	0.318	0.635	0.953	1.271	1.588	1.906	2.224	2.542	2.859	3.177
44	0.329	0.659	0.988	1.318	1.647	1.976	2.306	2.635	2.965	3.294
45	0.341	0.683	1.024	1.366	1.707	2.048	2.390	2.731	3.073	3.414
46	0.354	0.708	1.062	1.416	1.770	2.123	2.477	2.831	3.185	3.539
47	0.367	0.733	1.100	1.467	1.834	2.200	2.567	2.934	3.300	3.667
48	0.380	0.760	1.140	1.520	1.900	2.280	2.660	3.040	3.420	3.800
49	0.394	0.787	1.181	1.574	1.968	2.362	2.755	3.149	3.542	3.936
50	0.408	0.815	1.223	1.630	2.038	2.446	2.853	3.261	3.668	4.076
51	0.422	0.844	1.267	1.689	2.111	2.533	2.955	3.378	3.800	4.222
52	0.437	0.874	1.312	1.749	2.186	2.623	3.060	3.498	3.935	4.372
53	0.453	0.907	1.358	1.810	2.263	2.716	3.168	3.621	4.073	4.526
54	0.468	0.937	1.406	1.874	2.342	2.811	3.280	3.748	4.216	4.685
55	0.485	0.970	1.455	1.940	2.424	2.909	3.394	3.879	4.364	4.849
56	0.502	1.003	1.505	2.006	2.508	3.010	3.511	4.013	4.514	5.016
57	0.519	1.038	1.557	2.076	2.596	3.115	3.634	4.153	4.672	5.191
58	0.537	1.074	1.611	2.148	2.685	3.222	3.759	4.296	4.833	5.370
59	0.556	1.111	1.666	2.222	2.778	3.333	3.888	4.444	5.000	5.555
60	0.574	1.149	1.724	2.298	2.872	3.447	4.022	4.596	5.170	5.745
61	0.594	1.188	1.782	2.376	2.970	3.565	4.159	4.753	5.347	5.941
62	0.614	1.228	1.843	2.457	3.071	3.685	4.299	4.914	5.528	6.142
63	0.635	1.270	1.905	2.540	3.174	3.809	4.444	5.079	5.714	6.349
64	0.656	1.313	1.969	2.625	3.282	3.938	4.594	5.250	5.907	6.563
65	0.678	1.356	2.035	2.713	3.391	4.069	4.747	5.426	6.104	6.782
66	0.701	1.402	2.103	2.804	3.504	4.205	4.906	5.607	6.308	7.009
67	0.724	1.448	2.172	2.896	3.620	4.345	5.069	5.793	6.517	7.241
68	0.748	1.496	2.244	2.992	3.740	4.488	5.236	5.984	6.732	7.480
69	0.773	1.545	2.318	3.090	3.863	4.636	5.408	6.181	6.953	7.726
70	0.798	1.596	2.394	3.192	3.990	4.788	5.586	6.384	7.182	7.980
71	0.824	1.648	2.472	3.296	4.120	4.944	5.768	6.592	7.416	8.240
72	0.851	1.702	2.552	3.403	4.254	5.105	5.956	6.806	7.657	8.508
73	0.878	1.756	2.635	3.513	4.391	5.269	6.147	7.026	7.904	8.782
74	0.907	1.813	2.720	3.626	4.533	5.440	6.346	7.253	8.159	9.066

# 120 METALLURGISTS AND CHEMISTS' HANDBOOK

## WEIGHT OF A CUBIC FOOT OF AQUEOUS VAPOR AT DIFFERENT TEMPERATURES AND SATURATIONS (IN GRAINS). *Continued*

Temp., °F.	Percentage of saturation									
	10	20	30	40	50	60	70	80	90	100
	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.
75	0.936	1.871	2.807	3.742	4.678	5.614	6.549	7.485	8.420	9.356
76	0.966	1.931	2.896	3.862	4.828	5.793	6.758	7.724	8.690	9.655
77	0.996	1.992	2.989	3.985	4.981	5.977	6.973	7.970	8.966	9.962
78	1.028	2.055	3.083	4.111	5.138	6.166	7.194	8.222	9.249	10.277
79	1.060	2.120	3.180	4.240	5.300	6.361	7.421	8.481	9.541	10.601
80	1.093	2.187	3.280	4.374	5.467	6.560	7.654	8.747	9.841	10.934
81	1.128	2.255	3.382	4.510	5.638	6.765	7.892	9.020	10.148	11.275
82	1.163	2.325	3.483	4.650	5.813	6.976	8.138	9.301	10.463	11.626
83	1.199	2.397	3.596	4.795	5.994	7.192	8.391	9.590	10.788	11.987
84	1.236	2.471	3.707	4.942	6.178	7.414	8.649	9.885	11.120	12.356
85	1.274	2.547	3.821	5.094	6.368	7.642	8.915	10.189	11.462	12.736
86	1.313	2.625	3.938	5.251	6.564	7.877	9.189	10.502	11.814	13.127
87	1.353	2.705	4.058	5.410	6.763	8.116	9.468	10.821	12.173	13.520
88	1.394	2.787	4.181	5.575	6.968	8.362	9.756	11.150	12.543	13.937
89	1.436	2.872	4.308	5.744	7.180	8.615	10.051	11.487	12.923	14.359
90	1.479	2.959	4.437	5.916	7.395	8.874	10.353	11.832	13.311	14.790
91	1.523	3.047	4.570	6.094	7.617	9.140	10.664	12.187	13.711	15.234
92	1.569	3.138	4.707	6.276	7.844	9.413	10.982	12.551	14.120	15.689
93	1.616	3.231	4.846	6.462	8.078	9.693	11.308	12.924	14.540	16.155
94	1.663	3.327	4.990	6.654	8.317	9.980	11.644	13.307	14.971	16.634
95	1.712	3.425	5.137	6.850	8.562	10.274	11.987	13.699	15.412	17.124
96	1.763	3.525	5.288	7.050	8.813	10.576	12.338	14.101	15.863	17.626
97	1.814	3.628	5.443	7.257	9.071	10.885	12.699	14.514	16.328	18.142
98	1.867	3.734	5.601	7.468	9.336	11.203	13.070	14.937	16.804	18.671
99	1.921	3.842	5.764	7.685	9.606	11.527	13.448	15.370	17.291	19.212
100	1.977	3.952	5.930	7.906	9.883	11.860	13.836	15.813	17.789	19.766
101	2.034	4.067	6.100	8.134	10.168	12.201	14.234	16.268	18.302	20.335
102	2.092	4.183	6.275	8.367	10.458	12.550	14.642	16.734	18.825	20.917
103	2.151	4.303	6.454	8.606	10.757	12.908	15.060	17.211	19.363	21.514
104	2.212	4.425	6.638	8.850	11.062	13.275	15.488	17.700	19.912	22.125
105	2.275	4.550	6.825	9.100	11.375	13.650	15.925	18.200	20.475	22.750
106	2.339	4.678	7.018	9.357	11.696	14.035	16.374	18.714	21.053	23.392
107	2.405	4.809	7.214	9.619	12.024	14.429	16.834	19.238	21.643	24.048
108	2.472	4.944	7.416	9.888	12.360	14.832	17.304	19.776	22.248	24.720
109	2.541	5.082	7.622	10.163	12.704	15.245	17.786	20.326	22.867	25.408
110	2.611	5.222	7.834	10.445	13.056	15.667	18.278	20.890	23.501	26.112

TENSION OF AQUEOUS VAPOR AT VARIOUS TEMPERATURES<sup>1</sup>

Temperature, degrees C..	Tension of aque- ous vapor in mm.	Temperature, degrees C.	Tension of aque- ous vapor in mm.
0	4.525	21	18.505
1	4.867	22	19.675
2	5.231	23	20.909
3	5.619	24	22.211
4	6.032	25	23.582
5	6.471	26	25.026
6	6.939	27	26.547
7	7.436	28	28.148
8	7.964	29	29.832
9	8.525	30	31.602
10	9.126	31	33.464
11	9.751	32	35.419
12	10.421	33	37.473
13	11.130	34	39.630
14	11.882	35	41.893
15	12.677	36	44.268
16	13.519	37	46.758
17	14.409	38	49.368
18	15.351	39	52.103
19	16.345	40	54.969
20	17.396	.....	.....

<sup>1</sup> WINKLER, "Technical Gas Analysis."

BAROMETRIC CORRECTIONS

CORRECTIONS FOR TEMPERATURE  
(Mercury, Brass Scale Correct at 0°C.)

Temperature	Millimeters						
	730	740	750	760	770	780	790
15°	0.178	0.181	0.183	0.186	0.188	0.191	0.193
16	0.190	0.193	0.196	0.198	0.201	0.203	0.206
17	0.202	0.205	0.208	0.210	0.213	0.216	0.218
18	0.214	0.217	0.220	0.223	0.226	0.229	0.231
19	0.226	0.229	0.232	0.235	0.238	0.241	0.244
20	0.238	0.241	0.244	0.247	0.251	0.254	0.257
21	0.250	0.253	0.256	0.260	0.263	0.267	0.270
22	0.261	0.265	0.269	0.272	0.276	0.279	0.283
23	0.273	0.277	0.281	0.284	0.288	0.292	0.296
24	0.285	0.289	0.293	0.297	0.301	0.305	0.309

Corrections must be subtracted from observed readings, if reading at 19°C. is 760 mm., the corrected reading is 760 - 0.235. See also pp. 122 and 123.

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## EFFECT OF ALTITUDE ON BAROMETRIC PRESSURES<sup>1</sup>

Table of altitudes in feet above sea-level; with corresponding approximate barometric readings, atmospheric pressures and proportionate densities. (The capacity of an internal combustion engine at higher altitudes, as compared with its capacity at sea-level, is practically proportional to the atmospheric densities.)

Altitude in feet	Barometer in inches	Atmospheric pressure in pounds per square inch	Proportionate atmospheric density
0.00	30.0	14.72	1.00
500.0	29.5	14.45	0.98
1,000.0	28.9	14.18	0.96
1,500.0	28.4	13.94	0.94
2,000.0	27.9	13.69	0.93
2,500.0	27.4	13.45	0.91
3,000.0	26.9	13.20	0.89
4,000.0	26.0	12.75	0.86
5,000.0	25.1	12.30	0.83
6,000.0	24.2	11.85	0.80
7,000.0	23.3	11.44	0.77
8,000.0	22.5	11.04	0.75
9,000.0	21.7	10.65	0.73
10,000.0	20.9	10.26	0.70

<sup>1</sup> From the "Diesel Engine," Busch-Sulzer Bros. Diesel Engine Co.

## CORRECTION TO BE ADDED FOR CAPILLARITY<sup>1</sup>

Diameter tube in inches	Height of meniscus in inches							
	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08
0.15	0.024	0.047	0.069	0.092	0.116	.....	.....	.....
0.20	0.011	0.022	0.033	0.045	0.059	0.079	.....	.....
0.25	0.006	0.012	0.019	0.028	0.037	0.047	0.059	.....
0.30	0.004	0.008	0.013	0.018	0.023	0.029	0.035	0.042
0.35	.....	0.005	0.008	0.012	0.015	0.019	0.022	0.027
0.40	.....	0.004	0.006	0.008	0.010	0.012	0.014	0.016
0.45	.....	.....	0.003	0.005	0.007	0.008	0.010	0.012
0.50	.....	.....	0.002	0.004	0.005	0.006	0.006	0.007
0.55	.....	.....	0.001	0.002	0.003	0.004	0.005	0.005

From ELLENWOOD'S "Steam Charts," abbr. from Smithsonian table No. 103.

<sup>1</sup> Add the corrections to the observed reading.

BAROMETER CORRECTION FOR VARIATION IN  $\rho$ —CORRECT AT  
45° N. OR S. LATITUDE

	73	74	75	76	77	78	79
35° or 55°	0.065	0.066	0.066	0.067	0.068	0.069	0.070
40° or 50°	0.032	0.033	0.033	0.034	0.035	0.035	0.035

Subtract the correction for 35° and 40°.  
Add the correction for 50° and 55°.

## BATTERIES, E.M.F. OF STANDARD CELLS

Cell	Description	E.m.f.	Resist- ance
Bichromate	Zn and C in 1 vol. strong $\text{H}_2\text{SO}_4$ and 20 vol. sat. $\text{K}_2\text{Cr}_2\text{O}_7$ sol.	2.0	Very low
Bunsen.. . . .	Zn in 1 vol. strong $\text{H}_2\text{SO}_4$ ; 12 vol. $\text{H}_2\text{O}$ C in strong $\text{HNO}_3$ .	1.8-1.9	.....
Clark . . . . .	Zn amalgam and Hg in sat. $\text{ZnSO}_4$ sol	1.433	About 500
Daniell. . . . .	Zn in $\text{ZnSO}_4$ sol. or $\text{H}_2\text{SO}_4$ (1:12) Cu in sat $\text{CuSO}_4$ sol.	1.07-1.08	About 4
Grove. . . . .	Like Bunsen, C replaced by Pt.	1.8-1.9	.....
Leclanché	Zn and C in $\text{NH}_4\text{Cl}$ , C and $\text{MnO}_2$ .	1.5	0.25-0.4
Secondary. . . .	Pb and $\text{PbO}_2$ in $\text{H}_2\text{SO}_4$ of density 1.2	2.2-1.9	.....
Tucker. . . . .	Zn and C with sat. $\text{CaCl}_2$ sol.	1.4	.....
Weston. ....	Cd amalgam. and Hg in sat. $\text{CdSO}_4$ sol.	1.01828	About 500
Edison.....	$\text{CuO}$ and Zn in $\text{NaOH}$ .	1.12	0.02-0.09

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## HYDROMETER CONVERSION FACTORS

$$\begin{array}{l} \text{Liquids} \\ \text{lighter} \\ \text{than} \\ \text{water} \end{array} \left\{ \begin{array}{l} \frac{140}{\text{Bé.}^\circ + 130} = \text{sp. gr.} \\ \frac{140}{\text{sp. gr.}} - 130 = \text{Bé.}^\circ \end{array} \right.$$

$$\begin{array}{l} \text{Liquids} \\ \text{heavier} \\ \text{than} \\ \text{water} \end{array} \left\{ \begin{array}{l} \text{Sp. gr.} = \frac{145}{145 - \text{Bé.}^\circ} \\ \text{Bé.}^\circ = 145 - \frac{145}{\text{sp. gr.}} \end{array} \right.$$

To correct Bé. readings to 60°F.: Correct reading = observed reading +  $\frac{60 - t}{10}$

Apparently in order to make the hydrometer test for gasoline higher, further confusion in hydrometers was introduced in 1923 by the agreement of the American Petroleum Institute, the Bureau of Mines, and the Bureau of Standards that a scale based on the modulus 141.5 shall be used in the United States petroleum industry and shall be known as the A.P.I. scale.

The formula for converting specific gravity to A.P.I. is as follows:

$$\text{Degrees A.P.I.} = \frac{141.5}{\text{sp. gr. } 60^\circ/60^\circ\text{F.}} - 131.5$$

This scale differs from Baumé standard for liquids lighter than water in that the conversion modulus for the A.P.I. scale is 141.5 instead of 140.

$$\text{True sp. gr. } (60/60^\circ\text{F.}) = \frac{141.5}{131.5 + \text{A.P.I.}}$$

The relation between the U. S. Baumé scale and the A.P.I. scale at 60°F. is:

$$\text{Degrees A.P.I.} = 1.010714 \text{ deg. Bé.} - 0.10714$$

Thus 10°Bé. (140 mod.) corresponds to 10.0 A.P.I. (141.5 modulus)  
 30°Bé. (140 mod.) corresponds to 30.2 A.P.I. (141.5 modulus)  
 50°Bé. (140 mod.) corresponds to 50.4 A.P.I. (141.5 modulus)  
 70°Bé. (140 mod.) corresponds to 70.6 A.P.I. (141.5 modulus)  
 90°Bé. (140 mod.) corresponds to 90.8 A.P.I. (141.5 modulus)

For the Twaddell hydrometer:

$$\frac{\text{Tw.}^\circ}{200} + 1 = \text{sp. gr.}$$

For the Gay-Lussac (standardized at 4°C.):

$$\frac{100}{\text{G.-L.}^\circ + 100} = \text{sp. gr.}$$

$$\frac{100}{\text{sp. gr.}} - 100 = \text{G.-L.}^\circ$$

For the Sikes hydrometer: 1° = 0.002 of sp. gr.

For the Beck (12.5°C.) sp. gr. =  $\frac{170}{170 + \text{Beck}^\circ}$

For the Cartier (12.5°): sp. gr. =  $\frac{136}{126.1 + \text{Cart.}^\circ}$

For the Brix and the Fisher (15.6°C.): sp. gr. =  $\frac{400}{400 + n^\circ}$

CONVERSION TABLE FOR DEGREES BAUMÉ<sup>1</sup>  
(Liquids lighter than water<sup>2</sup>)

Degrees Baumé	Sp. gr.	Pounds in 1 gal. American <sup>3</sup>	Degrees Baumé	Sp. gr.	Pounds in 1 gal. American <sup>3</sup>
10	1.0000	8.33	43	0.8092	6.74
11	0.9929	8.27	44	0.8045	6.70
12	0.9859	8.21	45	0.8000	6.66
13	0.9790	8.16	46	0.7954	6.63
14	0.9722	8.10	47	0.7909	6.59
15	0.9655	8.04	48	0.7865	6.55
16	0.9589	7.99	49	0.7821	6.52
17	0.9523	7.93	50	0.7777	6.48
18	0.9459	7.88	51	0.7734	6.44
19	0.9395	7.83	52	0.7692	6.41
20	0.9333	7.78	53	0.7650	6.37
21	0.9271	7.72	54	0.7608	6.34
22	0.9210	7.67	55	0.7567	6.30
23	0.9150	7.62	56	0.7526	6.27
24	0.9090	7.57	57	0.7486	6.24
25	0.9032	7.53	58	0.7446	6.20
26	0.8974	7.48	59	0.7407	6.17
27	0.8917	7.43	60	0.7368	6.14
28	0.8860	7.38	61	0.7329	6.11
29	0.8805	7.34	62	0.7290	6.07
30	0.8750	7.29	63	0.7253	6.04
31	0.8695	7.24	64	0.7216	6.01
32	0.8641	7.20	65	0.7179	5.98
33	0.8588	7.15	66	0.7142	5.95
34	0.8536	7.11	67	0.7106	5.92
35	0.8484	7.07	68	0.7070	5.89
36	0.8433	7.03	69	0.7035	5.86
37	0.8383	6.98	70	0.7000	5.83
38	0.8333	6.94	75	0.6829	5.69
39	0.8284	6.90	80	0.6666	5.55
40	0.8235	6.86	85	0.6511	5.42
41	0.8187	6.82	90	0.6363	5.30
42	0.8139	6.78	95	0.6222	5.18

<sup>1</sup> The Baumé scale is entirely arbitrary, so various authorities give various values for the above table. These given above are from a table specially calculated for the "Petroleum Year Book, 1914" by TAGLIAPIETRA of New York.

<sup>2</sup> For liquids heavier than water, see the sulphuric acid table on pp. 126 to 133.

<sup>3</sup> Sp. gr.  $\times 10$  = pounds per imperial gallon.

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## SPECIFIC GRAVITY OF SULPHURIC ACID AT 60°F., COMPARED WITH WATER AT 60°F.

This table is the one approved and adopted as a standard by the Manufacturing Chemists Association of the United States. (See note on p. 133.)

Degrees Baumé	Sp. gr. at 60° 60°	Degrees Twaddell	Wt. of 1 cu. ft. in lb Avoir.	Per cent. H <sub>2</sub> SO <sub>4</sub>	Lb. of 66° acid in 1 cu. ft.	Melting (or freezing) point, °F.
0	1.0000	0.0	62.37	0.00	0.00	32.0
1	1.0069	1.4	62.80	1.02	0.68	31.2
2	1.0140	2.8	63.24	2.08	1.41	30.5
3	1.0211	4.2	63.69	3.13	2.14	29.8
4	1.0284	5.7	64.14	4.21	2.90	28.9
5	1.0357	7.1	64.60	5.28	3.66	28.1
6	1.0432	8.6	65.06	6.37	4.45	27.2
7	1.0507	10.1	65.53	7.45	5.24	26.3
8	1.0584	11.7	66.01	8.55	6.06	25.1
9	1.0662	13.2	66.50	9.66	6.89	24.0
10	1.0741	14.8	66.99	10.77	7.74	22.8
11	1.0821	16.4	67.49	11.89	8.61	21.5
12	1.0902	18.0	68.00	13.01	9.49	20.0
13	1.0985	19.7	68.51	14.13	10.39	18.3
14	1.1069	21.4	69.04	15.25	11.30	16.6
15	1.1154	23.1	69.57	16.38	12.23	14.7
16	1.1240	24.8	70.10	17.53	13.19	12.6
17	1.1328	26.6	70.65	18.71	14.18	10.2
18	1.1417	28.3	71.21	19.89	15.20	7.7
19	1.1508	30.2	71.78	21.07	16.23	4.8
20	1.1600	32.0	72.35	22.25	17.27	+1.6
21	1.1694	33.9	72.94	23.43	18.34	-1.8
22	1.1789	35.8	73.53	24.61	19.42	-6.0
23	1.1885	37.7	74.13	25.81	20.53	-11.0
24	1.1983	39.7	74.74	27.03	21.68	-16.0
25	1.2083	41.7	75.36	28.28	22.87	-23.0
26	1.2185	43.7	76.00	29.53	24.08	-30.0
27	1.2288	45.8	76.64	30.79	25.32	-39.0
28	1.2393	47.9	77.30	32.05	26.58	-49.0
29	1.2500	50.0	77.96	33.33	27.88	-61.0
30	1.2609	52.2	78.64	34.63	29.22	-74.0
31	1.2719	54.4	79.33	35.93	30.58	-82.0
32	1.2832	56.6	80.03	37.26	32.00	-96.0
33	1.2946	58.9	80.74	38.58	33.42	-97.0
34	1.3063	61.3	81.47	39.92	34.90	-91.0
35	1.3182	63.6	82.22	41.27	36.41	-81.0
36	1.3303	66.1	82.97	42.63	37.95	-70.0
37	1.3426	68.5	83.74	43.99	39.53	-60.0
38	1.3551	71.0	84.52	45.35	41.13	-53.0
39	1.3679	73.6	85.32	46.72	42.77	-47.0
40	1.3810	76.2	86.13	48.10	44.45	-41.0



### SPECIFIC GRAVITY OF SULPHURIC ACID AT 60°F., COMPARED WITH WATER AT 60°F.

This table is the one approved and adopted as a standard by the Manufacturing Chemists Association of the United States. (See note on p. 133.)

Degrees Baumé	Sp. gr. at 60°	Degrees Twaddell	Wt. of 1 cu. ft. in lb. Avoir.	Per cent. H <sub>2</sub> SO <sub>4</sub>	Lb. of 66° acid in 1 cu. ft.	Melting (or freezing) point, °F.
41	1.3942	78.8	86.96	49.47	46.16	-35.0
42	1.4078	81.6	87.80	50.87	47.92	-31.0
43	1.4216	84.3	88.67	52.26	49.72	-27.0
44	1.4356	87.1	89.54	53.66	51.56	-23.0
45	1.4500	90.0	90.44	55.07	53.44	-20.0
46	1.4646	92.9	91.35	56.48	55.36	-14.0
47	1.4796	95.9	92.28	57.90	57.33	-15.0
48	1.4948	99.0	93.23	59.32	59.34	-18.0
49	1.5104	102.1	94.20	60.75	61.40	-22.0
50	1.5263	105.3	95.20	62.18	63.52	-27.0
51	1.5426	108.5	96.21	63.66	65.72	-33.0
52	1.5591	111.8	97.24	65.13	67.96	-39.0
53	1.5761	115.2	98.30	66.64	70.28	-49.0
54	1.5934	118.7	99.38	68.13	72.66	-59.0
55	1.6111	122.2	100.48	69.65	75.10	
56	1.6292	125.8	101.61	71.17	77.60	
57	1.6477	129.5	102.77	72.75	80.23	
58	1.6667	133.3	103.95	74.36	82.95	
59	1.6860	137.2	105.16	75.99	85.75	-7.0
60	1.7059	141.2	106.40	77.67	88.68	+12.6
61	1.7262	145.2	107.66	79.43	91.76	+27.3
62	1.7470	149.4	108.96	81.30	95.06	+39.1
63	1.7683	153.7	110.29	83.34	98.63	+46.1
64	1.7901	158.0	111.65	85.66	102.63	+46.4
65	1.8125	162.5	113.05	88.65	107.54	+33.1
66	1.8354	167.1	114.47	93.19	114.47	-29.0

H<sub>2</sub>SO<sub>4</sub> · H<sub>2</sub>O = 63.2°Bé. approx. = 83.74 per cent. H<sub>2</sub>SO<sub>4</sub>.  
H<sub>2</sub>SO<sub>4</sub> · 2H<sub>2</sub>O = 56.9°Bé. approx. = 72.59 per cent. H<sub>2</sub>SO<sub>4</sub>.

#### Temperature Corrections

For each degree in observed temperature above 60°F. add the correction to the observed specific gravity to get the true specific gravity at 60°. For each degree below 60°, subtract.

For 10°Bé. acid, 0.029 Bé. or 0.00023 sp. gr. per deg. F.  
For 20°Bé. acid, 0.036 Bé. or 0.00034 sp. gr. per deg. F.  
For 30°Bé. acid, 0.035 Bé. or 0.00039 sp. gr. per deg. F.  
For 40°Bé. acid, 0.031 Bé. or 0.00041 sp. gr. per deg. F.  
For 50°Bé. acid, 0.028 Bé. or 0.00045 sp. gr. per deg. F.  
For 60°Bé. acid, 0.026 Bé. or 0.00053 sp. gr. per deg. F.  
For 63°Bé. acid, 0.026 Bé. or 0.00057 sp. gr. per deg. F.  
For 66°Bé. acid, 0.0235 Bé. or 0.00054 sp. gr. per deg. F.

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SPECIFIC GRAVITY OF SULPHURIC ACID<sup>1</sup> AT 15°C., COMPARED TO WATER AT 4°C.

Sp. gr. at. $\frac{15^{\circ}}{4^{\circ}}$	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO <sub>3</sub>	H <sub>2</sub> SO <sub>4</sub>	60°Bé. acid	50°Bé. acid
1.000	0.00	0	0.07	0.09	0.12	0.14
1.005	0.72	1	0.68	0.83	1.06	1.33
1.010	1.44	2	1.28	1.57	2.01	2.51
1.015	2.14	3	1.88	2.30	2.95	3.68
1.020	2.84	4	2.47	3.03	3.88	4.85
1.025	3.53	5	3.07	3.76	4.82	6.02
1.030	4.22	6	3.67	4.49	5.78	7.18
1.035	4.90	7	4.27	5.23	6.73	8.37
1.040	5.58	8	4.87	5.96	7.64	9.54
1.045	6.24	9	5.45	6.67	8.55	10.67
1.050	6.90	10	6.02	7.37	9.44	11.79
1.055	7.56	11	6.59	8.07	10.34	12.91
1.060	8.21	12	7.16	8.77	11.24	14.03
1.065	8.85	13	7.73	9.47	12.14	15.15
1.070	9.49	14	8.32	10.19	13.05	16.30
1.075	10.12	15	8.90	10.90	13.96	17.44
1.080	10.74	16	9.47	11.60	14.87	18.56
1.085	11.36	17	10.04	12.30	15.76	19.68
1.090	11.97	18	10.60	12.99	16.65	20.78
1.095	12.58	19	11.16	13.67	17.52	21.87
1.100	13.18	20	11.71	14.35	18.39	22.96
1.105	13.78	21	12.27	15.03	19.26	24.05
1.110	14.37	22	12.82	15.71	20.13	25.14
1.115	14.95	23	13.36	16.36	20.96	26.18
1.120	15.54	24	13.89	17.01	21.80	27.22
1.125	16.11	25	14.42	17.66	22.63	28.26
1.130	16.68	26	14.95	18.31	23.47	29.30
1.135	17.25	27	15.48	18.96	24.29	30.34
1.140	17.81	28	16.01	19.61	25.13	31.38
1.145	18.36	29	16.54	20.26	25.96	32.42
1.150	18.91	30	17.07	20.91	26.79	33.46
1.155	19.46	31	17.59	21.55	27.61	34.48
1.160	20.00	32	18.11	22.19	28.43	35.50
1.165	20.54	33	18.64	22.83	29.35	36.53
1.170	21.07	34	19.16	23.47	30.07	37.55
1.175	21.60	35	19.69	24.12	30.90	38.59

SPECIFIC GRAVITY OF SULPHURIC ACID<sup>1</sup> AT 15°C., COMPARED TO WATER AT 4°C. *Continued*

Sp. gr. at. 15° 4°	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO <sub>3</sub>	H <sub>2</sub> SO <sub>4</sub>	60°Bé. acid	50°Bé. acid
1.180	22.12	36	20.21	24.76	31.73	39.62
1.185	22.64	37	20.73	25.40	32.55	40.64
1.190	23.15	38	21.26	26.04	33.37	41.66
1.195	23.66	39	21.78	26.68	34.19	42.69
1.200	24.17	40	22.30	27.32	35.01	43.71
1.205	24.67	41	22.82	27.95	35.83	44.72
1.210	25.17	42	23.33	28.58	36.66	45.73
1.215	25.66	43	23.84	29.21	37.45	46.74
1.220	26.15	44	24.36	29.84	38.23	47.74
1.225	26.63	45	24.88	30.48	39.05	48.77
1.230	26.11	46	25.39	31.11	39.86	49.78
1.235	27.59	47	25.88	31.70	40.61	50.72
1.240	28.06	48	26.35	32.28	41.37	51.65
1.245	28.53	49	26.83	32.86	42.11	52.58
1.250	29.00	50	27.29	33.43	42.84	53.49
1.255	29.46	51	27.76	34.00	43.57	54.40
1.260	29.92	52	28.22	34.57	44.30	55.31
1.265	30.38	53	28.69	35.14	45.03	56.22
1.270	30.83	54	29.15	35.71	45.76	57.14
1.275	31.29	55	29.62	36.29	46.50	58.06
1.280	31.72	56	30.10	36.87	47.24	58.99
1.285	32.16	57	30.57	37.45	47.99	59.92
1.290	32.60	58	31.04	38.03	48.73	60.85
1.295	33.03	59	31.52	38.61	49.47	61.78
1.300	33.46	60	31.99	39.19	50.21	62.70
1.305	33.89	61	32.46	39.77	50.96	63.63
1.310	34.32	62	32.94	40.35	51.71	64.56
1.315	34.74	63	33.41	40.93	52.45	65.45
1.320	35.15	64	33.88	41.50	53.18	66.40
1.325	35.57	65	34.35	42.08	53.92	67.33
1.330	35.98	66	34.80	42.66	54.67	68.26
1.335	36.39	67	35.27	43.20	55.36	69.12
1.340	36.79	68	35.71	43.74	56.05	69.98
1.345	37.19	69	36.14	44.28	56.74	70.85
1.350	37.59	70	36.58	44.82	57.43	71.71
1.355	37.99	71	37.02	45.35	58.11	72.56

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SPECIFIC GRAVITY OF SULPHURIC ACID<sup>1</sup> AT 15°C., COMPARED TO WATER AT 4°C. *Continued*

Sp gr. at. 15° 4°	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO <sub>2</sub>	H <sub>2</sub> SO <sub>4</sub>	60°Bé. acid	50°Bé. acid
1 360	38 38	72	37.45	45.88	58.79	73.41
1 365	38.77	73	37.89	46.41	59.48	74.26
1 370	39.16	74	38.32	46.94	60.15	75.10
1.375	39.55	75	38.75	47.47	60.83	75.95
1.380	39.93	76	39.18	48.00	61.51	76.80
1 385	40.31	77	39.62	48.53	62.19	77.65
1 390	40.69	78	40.05	49.06	62.87	78.50
1 395	41.06	79	40.48	49.59	63.55	79.34
1 400	41.43	80	40.91	50.11	64.21	80.18
1 405	41 80	81	41.33	50.63	64.88	81.01
1.410	42.16	82	41.76	51.15	65.55	81.86
1.415	42 53	83	42.17	51.66	66.21	82.66
1.420	42 89	84	42.57	52.15	66.82	83.44
1.425	43 25	85	42.96	52.63	67.44	84.21
1 430	43 60	86	43.36	53.11	68.06	84.98
1 435	43 95	87	43.75	53.59	68.68	85.74
1 440	44 30	88	44.14	54.07	69.29	86.51
1 445	44 65	89	44.53	54.55	69.90	87.28
1.450	45 00	90	44.92	55.03	70.52	88.05
1 455	45 34	91	45.31	55.50	71.12	88.80
1 460	45.68	92	45.69	55.97	71.72	89.55
1 465	46 02	93	46.07	56.43	72.31	90.29
1 470	46 36	94	46.45	56.90	72.91	91.04
1 475	46.70	95	46.83	57.37	73.51	91.79
1 480	47.03	96	47.21	57.83	74.10	92.53
1.485	47 36	97	47.57	58.28	74.68	93.25
1.490	47 68	98	47.95	58.74	75.27	93.98
1.495	48.01	99	48.34	59.22	75.88	94.75
1.500	48.33	100	48.73	59.70	76.50	95.52
1.505	48.65	101	49.12	60.18	77.12	96.29
1.510	48.97	102	49.51	60.65	77.72	97.04
1.515	49.29	103	49.89	61.12	78.32	97.79
1.520	49.60	104	50.28	61.59	78.93	98.54
1.525	49.92	105	50.66	62.06	79.52	99.30
1.530	50.23	106	51.04	62.53	80.13	100.05

SPECIFIC GRAVITY OF SULPHURIC ACID<sup>1</sup> AT 15°C., COMPARED TO WATER AT 4°C. *Continued*

Sp. gr. at. 15° 4°	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO <sub>3</sub>	H <sub>2</sub> SO <sub>4</sub>	60°Bé. acid	50°Bé. acid
1.535	50.54	107	51.43	63.00	80.73	100.80
1.540	50.84	108	51.78	63.43	81.28	101.49
1.545	51.15	109	52.12	63.85	81.81	102.16
1.550	51.46	110	52.46	64.26	82.34	102.82
1.555	51.76	111	52.79	64.67	82.87	103.47
1.560	52.05	112	53.12	65.08	83.39	104.13
1.565	52.35	113	53.46	65.49	83.92	104.78
1.570	52.64	114	53.80	65.90	84.44	105.44
1.575	52.94	115	54.13	66.30	84.95	106.08
1.580	53.23	116	54.46	66.71	85.48	106.73
1.585	53.52	117	54.80	67.13	86.03	107.41
1.590	53.81	118	55.18	67.59	86.62	108.14
1.595	54.09	119	55.55	68.05	87.20	108.88
1.600	54.37	120	55.93	68.51	87.79	109.62
1.605	54.66	121	56.30	68.97	88.38	110.35
1.610	54.94	122	56.68	69.43	88.97	111.09
1.615	55.22	123	57.05	69.89	89.56	111.82
1.620	55.49	124	57.40	70.32	90.11	112.51
1.625	55.77	125	57.75	70.74	90.65	113.18
1.630	56.04	126	58.09	71.16	91.19	113.86
1.635	56.32	127	58.43	71.57	91.71	114.51
1.640	56.59	128	58.77	71.99	92.25	115.18
1.645	56.86	129	59.10	72.40	92.77	115.84
1.650	57.13	130	59.45	72.82	93.29	116.51
1.655	57.39	131	59.78	73.23	93.81	117.17
1.660	57.65	132	60.11	73.64	94.36	117.82
1.665	57.91	133	60.46	74.07	94.92	118.51
1.670	58.17	134	60.82	74.51	95.48	119.22
1.675	58.43	135	61.20	74.97	96.07	119.95
1.680	58.69	136	61.57	75.42	96.65	120.67
1.685	58.95	137	61.93	75.86	97.21	121.38
1.690	59.20	138	62.29	76.30	97.77	122.08
1.695	59.46	139	62.64	76.73	98.32	122.77
1.700	59.71	140	63.00	77.17	98.89	123.47
1.705	59.96	141	63.35	77.60	99.44	124.16
1.710	60.20	142	63.70	78.04	100.00	124.86

# 132 METALLURGISTS AND CHEMISTS' HANDBOOK

SPECIFIC GRAVITY OF SULPHURIC ACID<sup>1</sup> AT 15°C., COMPARED TO  
WATER AT 4°C. *Continued*

Sp. gr. at. 15° 4°	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO <sub>3</sub>	H <sub>2</sub> SO <sub>4</sub>	60°Bé. acid	50°Bé. acid
1.715	60.45	143	64.07	78.48	100.56	125.57
1.720	60.70	144	64.43	78.92	101.13	126.27
1.725	60.94	145	64.78	79.36	101.69	126.98
1.730	61.18	146	65.14	79.80	102.25	127.68
1.735	61.42	147	65.50	80.24	102.82	128.38
1.740	61.66	148	65.86	80.68	103.38	129.09
1.745	61.90	149	66.22	81.12	103.95	129.79
1.750	62.14	150	66.58	81.56	104.52	130.49
1.755	62.38	151	66.94	82.00	105.08	131.20
1.760	62.61	152	67.30	82.44	105.64	131.90
1.765	62.85	153	67.65	82.88	106.21	132.61
1.770	63.08	154	68.02	83.32	106.77	133.31
1.775	63.31	155	68.49	83.90	107.51	134.24
1.780	63.54	156	68.98	84.50	108.27	135.20
1.785	63.77	157	69.47	85.10	109.05	136.16
1.790	63.99	158	69.96	85.70	109.82	137.14
1.795	64.22	159	70.45	86.30	110.58	138.08
1.800	64.45	160	70.94	86.90	111.35	139.06
1.805	64.67	161	71.50	87.60	112.25	140.16
1.810	64.89	162	72.08	88.30	113.15	141.28
1.815	65.11	163	72.69	89.05	114.11	142.48
1.820	65.33	164	73.51	90.05	115.33	144.08
1.821	65.38	..	73.63	90.20	115.59	144.32
1.822	65.42	..	73.80	90.40	115.84	144.64
1.823	65.46	..	73.96	90.60	116.10	144.96
1.824	65.50	..	74.12	90.80	116.35	145.28
1.825	65.55	165	74.29	91.00	116.61	145.60
1.826	65.59	..	74.49	91.25	116.93	146.00
1.827	65.64	..	74.69	91.50	117.25	146.40
1.828	65.68	..	74.86	91.70	117.51	146.72
1.829	65.72	..	75.03	91.90	117.76	147.04
1.830	65.76	166	75.19	92.10	118.02	147.36
1.831	65.80	..	75.35	92.30	118.27	147.68
1.828	65.85	..	75.53	92.52	118.56	148.03
1.833	65.89	..	75.72	92.75	118.85	148.40

SPECIFIC GRAVITY OF SULPHURIC ACID<sup>1</sup> AT 15°C., COMPARED TO WATER AT 4°C. *Continued*

Sp. gr. at. 15° 4°	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO <sub>3</sub>	H <sub>2</sub> SO <sub>4</sub>	60° Bé. acid	50° Bé. acid
1.834	65.94	.....	75.96	93.05	119.23	148.88
1.835	65.98	167.	76.27	93.43	119.72	149.49
1.836	66.03	.....	76.57	93.80	120.19	150.08
1.837	66.07	.....	76.90	94.20	120.71	150.72
1.838	66.11	.....	77.23	94.60	121.22	151.36
1.839	66.16	.....	77.55	95.00	121.74	152.00
1.840	66.20	168	78.04	95.60	122.51	152.96
1.8405	66.22	.....	78.33	95.95	122.96	153.52
1.8410	66.24	.....	79.19	97.00	124.30	155.20
1.8415	66.26	.....	79.76	97.70	125.20	156.32
1.8410	66.24	.....	80.16	98.20	125.84	157.12
1.8405	66.22	.....	80.57	98.70	126.48	157.92
1.8400	66.20	.....	80.98	99.20	127.12	158.72
1.8395	66.18	.....	81.18	99.45	127.44	159.12
1.8390	66.16	.....	81.39	99.70	127.76	159.52
1.8385	66.14	.....	81.59	99.95	128.08	159.92

<sup>1</sup> According to LUNGE and ISLER, and LUNGE and NAEF. LUNGE, "The Manufacture of Sulphuric Acid and Alkali," D. VAN NOSTRAND & Co., New York.

To reduce specific gravities observed at other temperatures than 15°C. to 15°C., roughly: For each degree above or below 15°, add to or subtract from the specific gravity observed:

0.0006 with acids to 1.170

0.0007 with acids from 1.170 to 1.450

0.0008 with acids from 1.450 to 1.580

0.0009 with acids from 1.580 to 1.750

0.0010 with acids from 1.750 to 1.840

	Per cent. H <sub>2</sub> SO <sub>4</sub>	Per cent. 60° acid	Per cent. 60° acid	Boils at	Melts at	Sp. gr.
66° acid =	93.19	= 100.00	= 119.98	538°F.	- 29°F.	1.8354
60° acid =	77.67	= 83.35	= 100.00	386°F.	+ 12°F.	1.7059
50° acid =	62.18	= 66.72	= 80.66	295°F.	- 27°F.	1.5263

NOTE.—The table given on pp. 128 to 133 is used by the dye-makers, that on pp. 126 and 127 by the acid manufacturers and powder plants. The differences are in the third or fourth figures and are probably less than the errors of observation. The New Jersey Zinc Co. uses figures differing slightly from both tables.

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## SPECIFIC GRAVITY OF HYDROCHLORIC ACID

Sp. gr. 15° 4°	Degrees Baumé	Degrees Twaddell	100 parts acid contain by weight			
			Per cent., HCl	Per cent., 18° acid	Per cent., 20° acid	Per cent., 22° acid
1.000	0.00	0 0	0.16	0.57	0.49	0.45
1.005	0.72	1	1.15	4.08	3.58	3.25
1.010	1.44	2	2.14	7.60	6.66	6.04
1.015	2.14	3	3.12	11.08	9.71	8.81
1.020	2.84	4	4.13	14.67	12.86	11.67
1.025	3.53	5	5.15	18.30	16.04	14.55
1.030	4.22	6	6.15	21.85	19.16	17.38
1.035	4.90	7	7.15	25.40	22.27	20.20
1.040	5.58	8	8.16	28.99	25.42	23.06
1.045	6.24	9	9.16	32.55	28.53	25.88
1.050	6.90	10	10.17	36.14	31.68	28.74
1.055	7.56	11	11.18	39.73	34.82	31.59
1.060	8.21	12	12.19	43.32	37.97	34.44
1.065	8.85	13	13.19	46.87	41.09	37.27
1.070	9.49	14	14.17	50.35	44.14	40.04
1.075	10.12	15	15.16	53.87	47.22	42.84
1.080	10.74	16	16.15	57.39	50.31	45.63
1.085	11.36	17	17.13	60.87	53.36	48.40
1.090	11.97	18	18.11	64.35	56.41	51.17
1.095	12.58	19	19.06	67.73	59.37	53.86
1.100	13.18	20	20.01	71.11	62.33	56.54
1.105	13.78	21	20.97	74.52	65.32	59.26
1.110	14.37	22	21.92	77.89	68.28	61.94
1.115	14.95	23	22.86	81.23	71.21	64.60
1.120	15.54	24	23.82	84.64	74.20	67.31
1.125	16.11	25	24.78	88.06	77.19	70.02
1.130	16.68	26	25.75	91.50	80.21	72.76
1.135	17.25	27	26.70	94.88	83.18	75.45
1.140	17.81	28	27.66	98.29	86.17	78.16
1.145	18.36	29	28.61	101.67	87.66	79.51
1.150	18.91	30	29.57	105.08	92.11	83.55
1.155	19.46	31	30.55	108.58	95.17	86.32
1.160	20.00	32	31.52	112.01	98.19	89.07
1.165	20.54	33	32.49	115.46	101.21	91.81
1.170	21.07	34	33.46	118.91	104.24	94.55
1.175	21.60	35	34.42	122.32	107.22	97.26
1.180	22.12	36	35.39	125.76	110.24	100.00
1.185	22.64	37	36.31	129.03	131.11	102.60
1.190	23.15	38	37.23	132.30	115.98	105.20
1.195	23.66	39	38.16	135.61	118.87	107.83
1.200	24.17	40	39.11	138.98	121.84	110.51

This table is taken from Lunge. Other authorities differ, giving in one case as much as 40.78 per cent. of HCl in 1.20 sp. gr. acid. That acid of 0°Bé. can contain 0.16 HCl is due to taking the sp. gr. at 15°C. as compared with water at 4°C.



## SPECIFIC GRAVITY OF NITRIC ACID AT 15° COMPARED WITH WATER AT 4°

Sp. gr. 15° 4°	Degrees Baumé	Degrees Twaddell	100 parts of acid contain by weight				
			N <sub>2</sub> O <sub>5</sub>	HNO <sub>3</sub>	38° acid	40° acid	48.5° acid
1.000	0.00	0	0.08	0.10	0.19	0.16	0.10
1.005	0.72	1	0.85	1.00	1.89	1.61	1.03
1.010	1.44	2	1.62	1.90	3.60	3.07	1.95
1.015	2.14	3	2.39	2.80	5.30	4.52	2.87
1.020	2.84	4	3.17	3.70	7.01	5.98	3.79
1.025	3.53	5	3.94	4.60	8.71	7.43	4.72
1.030	4.22	6	4.71	5.50	10.40	8.88	5.64
1.035	4.90	7	5.47	6.38	12.08	10.30	6.54
1.040	5.58	8	6.22	7.26	13.75	11.72	7.45
1.045	6.24	9	6.97	8.13	15.40	13.13	8.34
1.050	6.90	10	7.71	8.99	17.03	14.52	9.22
1.055	7.56	11	8.43	9.84	18.64	15.89	10.09
1.060	8.21	12	9.15	10.68	20.23	17.25	10.95
1.065	8.85	13	9.87	11.51	21.80	18.59	11.81
1.070	9.49	14	10.57	12.33	23.35	19.91	12.65
1.075	10.12	15	11.27	13.15	24.91	21.24	13.49
1.080	10.74	16	11.96	13.95	26.42	22.53	14.31
1.085	11.36	17	12.64	14.74	27.92	23.80	15.12
1.090	11.97	18	13.31	15.53	29.41	25.08	15.93
1.095	12.58	19	13.99	16.32	30.91	26.35	16.74
1.100	13.18	20	14.67	17.11	32.41	27.63	17.55
1.105	13.78	21	15.34	17.89	33.89	28.89	18.35
1.110	14.37	22	16.00	18.67	35.36	30.15	19.15
1.115	14.95	23	16.67	19.45	36.84	31.41	19.95
1.120	15.54	24	17.34	20.23	38.31	32.67	20.75
1.125	16.11	25	18.00	21.00	39.77	33.91	21.54
1.130	16.68	26	18.66	21.77	41.23	35.16	22.33
1.135	17.25	27	19.32	22.54	42.69	36.40	23.12
1.140	17.81	28	19.98	23.31	44.15	37.65	23.91
1.145	18.36	29	20.64	24.08	45.61	38.89	24.70
1.150	18.91	30	21.29	24.84	47.05	40.12	25.48
1.155	19.46	31	21.94	25.60	48.49	41.35	26.26
1.160	20.00	32	22.60	26.36	49.92	42.57	27.04
1.165	20.54	33	23.25	27.12	51.36	43.80	27.82
1.170	21.07	34	23.90	27.88	52.80	45.03	28.59
1.175	21.60	35	24.54	28.63	54.22	46.24	29.36
1.180	22.12	36	25.18	29.38	55.64	47.45	30.13

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SPECIFIC GRAVITY OF NITRIC ACID AT 15° COMPARED WITH  
WATER AT 4°. *Continued*

Sp. gr., 15° 4°	Degrees Baumé	Degrees Twaddell	100 parts of acid contain by weight				
			N <sub>2</sub> O <sub>5</sub>	HNO <sub>3</sub>	38° acid	40° acid	48.5° acid
1.185	22.64	37	25.83	30.13	57.07	48.66	30.90
1.190	23.15	38	26.47	30.88	58.49	49.87	31.67
1.195	23.66	39	27.10	31.62	59.89	51.07	32.43
1.200	24.17	40	27.74	32.36	61.29	52.26	33.19
1.205	24.67	41	28.36	33.09	62.67	53.23	33.94
1.210	25.17	42	28.99	33.82	64.05	54.21	34.69
1.215	25.66	43	29.61	34.55	65.44	55.18	35.44
1.220	26.15	44	30.24	35.28	66.82	56.16	36.18
1.225	26.63	45	30.88	36.03	68.24	57.64	36.95
1.230	27.11	46	31.53	36.78	69.66	59.13	37.72
1.235	27.59	47	32.17	37.53	71.08	60.61	38.49
1.240	28.06	48	32.82	38.29	72.52	61.84	39.27
1.245	28.53	49	33.47	39.05	73.96	63.07	40.05
1.250	29.00	50	34.13	39.82	75.42	64.31	40.84
1.255	29.46	51	34.78	40.58	76.86	65.54	41.62
1.260	29.92	52	35.44	41.34	78.30	66.76	42.40
1.265	30.38	53	36.09	42.10	79.74	67.99	43.18
1.270	30.83	54	36.75	42.87	81.20	69.23	43.97
1.275	31.29	55	37.41	43.64	82.65	70.48	44.76
1.280	31.72	56	38.07	44.41	84.11	71.72	45.55
1.285	32.16	57	38.73	45.18	85.57	72.96	46.34
1.290	32.60	58	39.39	45.95	87.03	74.21	47.13
1.295	33.13	59	40.05	46.72	88.48	75.45	47.92
1.300	33.46	60	40.71	47.49	89.94	76.70	48.71
1.305	33.89	61	41.37	48.28	91.40	77.94	49.50
1.310	34.32	62	42.06	49.07	92.94	79.25	50.33
1.315	34.74	63	42.76	48.89	94.49	80.57	51.17
1.320	35.15	64	43.47	50.71	96.05	81.90	52.01
1.325	35.57	65	44.17	51.53	97.60	83.22	52.85
1.330	35.98	66	44.89	52.37	99.19	84.58	53.71
1.335	36.39	67	45.62	53.22	100.80	85.95	54.58
1.340	36.79	68	46.35	54.07	102.41	87.32	55.46
1.345	37.19	69	47.08	54.93	104.04	88.71	56.34
1.350	37.59	70	47.82	55.79	105.67	90.10	57.22
1.355	37.99	71	48.57	56.66	107.31	91.51	58.11

**SPECIFIC GRAVITY OF NITRIC ACID AT 15° COMPARED WITH  
WATER AT 4°. *Continued***

Sp. gr., 15° 4°	Degrees Baumé	Degrees Twaddell	100 parts of acid contain by weight				
			N <sub>2</sub> O <sub>5</sub>	HNO <sub>3</sub>	38° acid	40° acid	48.5° acid
1.360	38.38	72	49.35	57.57	109.03	92.97	59.05
1.365	38.77	73	50.13	58.48	110.75	94.44	59.98
1.370	39.16	74	50.91	59.39	112.48	95.91	60.91
1.375	39.55	75	51.69	60.30	114.20	97.38	61.85
1.380	39.93	76	52.52	61.27	116.04	98.95	62.84
1.385	40.31	77	53.35	62.24	117.88	100.51	63.84
1.390	40.69	78	54.20	63.23	119.75	102.12	64.85
1.395	41.06	79	55.07	64.25	121.68	103.76	65.90
1.400	41.43	80	55.97	65.30	123.67	105.46	66.97
1.405	41.80	81	56.92	66.40	125.75	107.24	68.10
1.410	42.16	82	57.86	67.50	127.84	109.01	69.23
1.415	42.53	83	58.83	68.63	129.98	110.84	70.39
1.420	42.89	84	59.83	69.80	132.19	112.73	71.59
1.425	43.25	85	60.84	70.98	134.43	114.63	72.80
1.430	43.60	86	61.86	72.17	136.68	116.55	74.02
1.435	43.95	87	62.91	73.39	138.99	118.52	75.27
1.440	44.30	88	64.01	74.68	141.44	120.61	76.59
1.445	44.65	89	65.13	75.98	143.90	122.71	77.93
1.450	45.00	90	66.24	77.28	146.36	124.81	79.26
1.455	45.34	91	67.38	78.60	148.86	126.94	80.62
1.460	45.68	92	68.56	79.98	151.47	129.17	82.03
1.465	46.02	93	69.79	81.42	154.20	131.49	83.51
1.470	46.36	94	71.06	82.90	157.00	133.88	85.03
1.475	46.70	95	72.39	84.45	159.04	136.39	86.62
1.480	47.03	96	73.76	86.05	162.97	138.97	88.26
1.485	47.36	97	75.13	87.70	166.09	141.63	89.95
1.490	47.68	98	76.80	89.60	169.69	144.70	91.90
1.495	48.01	99	78.52	91.60	173.48	147.93	93.95
1.500	48.33	100	80.65	94.09	178.19	151.99	96.50
1.505	48.65	101	82.63	96.39	182.55	155.67	98.86
1.510	48.97	102	84.09	98.10	185.79	158.43	100.62
1.515	49.29	103	84.92	99.07	187.63	160.00	100.61
1.520	49.60	104	85.44	99.67	188.77	160.97	102.23

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## SPECIFIC GRAVITY OF AMMONIA WATER AT 60°F. COMPARED WITH WATER AT 60°F.

Sp. gr. 60° 60°	Degrees Baumé	Per cent., NH <sub>3</sub>	Sp. gr. 60° 60°	Degrees Baumé	Per cent., NH <sub>3</sub>
1.0000	10.00	0.00	0.9333	20.00	17.76
0.9964	10.50	0.80	0.9302	20.50	18.72
0.9929	11.00	1.62	0.9272	21.00	19.68
0.9894	11.50	2.46	0.9241	21.50	20.64
0.9859	12.00	3.30	0.9211	22.00	21.60
0.9825	12.50	4.16	0.9180	22.50	22.56
0.9790	13.00	5.02	0.9150	23.00	23.52
0.9756	13.50	5.88	0.9121	23.50	24.50
0.9722	14.00	6.74	0.9091	24.00	25.48
0.9689	14.50	7.61	0.9061	24.50	26.46
0.9655	15.00	8.49	0.9032	25.00	27.44
0.9622	15.50	9.38	0.9003	25.50	28.42
0.9589	16.00	10.28	0.8974	26.00	29.40
0.9556	16.50	11.18	0.8946	26.50	30.38
0.9524	17.00	12.10	0.8917	27.00	31.36
0.9492	17.50	13.02	0.8889	27.50	32.34
0.9459	18.00	13.96	0.8861	28.00	33.32
0.9428	18.50	14.90	0.8833	28.50	34.30
0.9396	19.00	15.84	0.8805	29.00	35.28
0.9365	19.50	16.80			

Corrections to be added for each degree below 60°F., in degrees Baumé

Corrections to be subtracted for each degree above 60°F., in degrees Baumé

Bé.°	40°F.	50°F.	70°F.	80°	90°	100°F.
14	0.015	0.017	0.020	0.022	0.024	0.026
16	0.021	0.023	0.026	0.028	0.030	0.032
18	0.027	0.029	0.031	0.033	0.035	0.037
20	0.033	0.036	0.037	0.038	0.040	0.042
22	0.039	0.042	0.043	0.045	0.047	
26	0.053	0.057	0.057	0.059		

The above table has been approved by the Manufacturing Chemists' Association of the United States and is reprinted by its courtesy.

**SPECIFIC GRAVITY OF CAUSTIC POTASH SOLUTIONS AT 15°C.<sup>1</sup>**  
(Grams KOH per 100 grams solution)

Sp. gr.	Per cent., KOH	Sp. gr.	Per cent., KOH	Sp. gr.	Per cent., KOH
1.036	5	1.288	30	1.604	55
1.077	10	1.349	35	1.667	60
1.124	15	1.411	40	1.729	65
1.175	20	1.475	45	1.790	70
1.230	25	1.539	50	.....	.....

<sup>1</sup> This and the succeeding 14 tables are from CREMER & BICKNELL's *Chemical and Metallurgical Handbook*. They are originally from the work of Kohlrausch and Holborn, Gerlach, Schiff, etc.

**SPECIFIC GRAVITY OF CAUSTIC SODA SOLUTIONS AT 15°C.**

Sp. gr.	Per cent., NaOH	Sp. gr.	Per cent., NaOH	Sp. gr.	Per cent., NaOH
1.059	5	1.332	30	1.591	55
1.115	10	1.384	35	1.643	60
1.170	15	1.437	40	1.695	65
1.225	20	1.488	45	1.748	70
1.279	25	1.540	50	.....	.....

**SPECIFIC GRAVITY OF HYDROFLUOSILICIC ACID AT 15°C.**

Sp. gr.	Per cent., H <sub>2</sub> SiF <sub>6</sub>	Sp. gr.	Per cent., H <sub>2</sub> SiF <sub>6</sub>	Sp. gr.	Per cent., H <sub>2</sub> SiF <sub>6</sub>
1.0407	5	1.1748	20	1.2742	30
1.0834	10	1.2235	25	1.3162	34
1.1281	15				

**SPECIFIC GRAVITY OF SODIUM CARBONATE SOLUTIONS AT 15°C.**

Sp. gr.	Per cent., Na <sub>2</sub> CO <sub>3</sub>	Sp. gr.	Per cent., Na <sub>2</sub> CO <sub>3</sub>	Sp. gr.	Per cent., Na <sub>2</sub> CO <sub>3</sub>
1.01050	1	1.06309	6	1.11655	11
1.02101	2	1.07369	7	1.12740	12
1.03151	3	1.08430	8	1.13845	13
1.04201	4	1.09500	9	1.14930	14
1.05255	5	1.10571	10	1.15360	14.354

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## SPECIFIC GRAVITY OF CALCIUM CHLORIDE SOLUTIONS AT 15°C.

Sp. gr.	Per cent., CaCl <sub>2</sub>	Sp. gr.	Per cent., CaCl <sub>2</sub>	Sp. gr.	Per cent., CaCl <sub>2</sub>
1.01704	2	1.14332	16	1.28789	30
1.03407	4	1.16277	18	1.31045	32
1.05146	6	1.18222	20	1.33302	34
1.06921	8	1.20279	22	1.35610	36
1.08695	10	1.22336	24	1.37970	38
1.10561	12	1.24450	26	1.40330	40
1.12427	14	1.26619	28	1.41104	46.46

## SPECIFIC GRAVITY OF ZINC CHLORIDE AT 19.5°C.

Sp. gr.	Per cent., ZnCl <sub>2</sub>	Sp. gr.	Per cent., ZnCl <sub>2</sub>	Sp. gr.	Per cent., ZnCl <sub>2</sub>
1.045	5	1.238	25	1.488	45
1.091	10	1.291	30	1.566	50
1.137	15	1.352	35	1.650	55
1.187	20	1.420	40	1.740	60

## SPECIFIC GRAVITY OF FERRIC CHLORIDE SOLUTIONS AT 17.5°C.

Sp. gr.	Per cent., FeCl <sub>3</sub>	Sp. gr.	Per cent., FeCl <sub>3</sub>	Sp. gr.	Per cent., FeCl <sub>3</sub>
1.0146	2	1.1746	22	1.3870	42
1.0292	4	1.1950	24	1.4118	44
1.0439	6	1.2155	26	1.4367	46
1.0587	8	1.2365	28	1.4617	48
1.0734	10	1.2568	30	1.4867	50
1.0894	12	1.2778	32	1.5153	52
1.1054	14	1.2988	34	1.5439	54
1.1215	16	1.3199	36	1.5729	56
1.1378	18	1.3411	38	1.6023	58
1.1542	20	1.3622	40	1.6317	60

## SPECIFIC GRAVITY OF CUPROUS CHLORIDE SOLUTIONS AT 17.5°C.

Sp. gr.	Per cent., CuCl <sub>2</sub>	Sp. gr.	Per cent., CuCl <sub>2</sub>	Sp. gr.	Per cent., CuCl <sub>2</sub>
1.0182	2	1.1696	16	1.3618	30
1.0364	4	1.1958	18	1.3950	32
1.0548	6	1.2223	20	1.4287	34
1.0734	8	1.2501	22	1.4615	36
1.0920	10	1.2779	24	1.4949	38
1.1178	12	1.3058	26	1.5284	40
1.1436	14	1.3338	28	.....	.....

## SPECIFIC GRAVITY OF LEAD ACETATE SOLUTIONS AT 15°C.

Sp. gr.	Per cent., PbA <sub>2</sub>	Sp. gr.	Per cent., PbA <sub>2</sub>	Sp. gr.	Per cent., PbA <sub>2</sub>
1.0127	2	1.1384	20	1.2967	38
1.0255	4	1.1544	22	1.3163	40
1.0386	6	1.1704	24	1.3376	42
1.0520	8	1.1869	26	1.3588	44
1.0654	10	1.2040	28	1.3810	46
1.0796	12	1.2211	30	1.4041	48
1.0939	14	1.2395	32	1.4271	50
1.1084	16	1.2578	34	.....	.....
1.1234	18	1.2768	36	.....	.....

## SPECIFIC GRAVITY OF FERRIC SULPHATE SOLUTIONS AT 17.5°C.

Sp. gr.	Per cent., Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Sp. gr.	Per cent., Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Sp. gr.	Per cent., Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>
1.0170	2	1.2066	22	1.4824	42
1.0340	4	1.2306	24	1.5142	44
1.0512	6	1.2559	26	1.5468	46
1.0684	8	1.2825	28	1.5808	48
1.0854	10	1.3090	30	1.6148	50
1.1042	12	1.3368	32	1.6508	52
1.1230	14	1.3646	34	1.6868	54
1.1424	16	1.3927	36	1.7241	56
1.1624	18	1.4217	38	1.7623	58
1.1826	20	1.4506	40	1.8006	60

SPECIFIC GRAVITY OF FeSO<sub>4</sub>·7H<sub>2</sub>O; CuSO<sub>4</sub>·5H<sub>2</sub>O AND ZnSO<sub>4</sub>·7H<sub>2</sub>O SOLUTIONS AT 15°C.

Sp. gr.	Per cent., ZnSO <sub>4</sub> ·7H <sub>2</sub> O	Sp. gr.	Per cent., CuSO <sub>4</sub> ·5H <sub>2</sub> O	Sp. gr.	Per cent., FeSO <sub>4</sub> ·7H <sub>2</sub> O
1.0288	5	1.0126	2	1.011	2
1.0593	10	1.0254	4	1.021	4
1.0905	15	1.0384	6	1.032	6
1.1236	20	1.0516	8	1.043	8
1.1574	25	1.0649	10	1.054	10
1.1933	30	1.0785	12	1.065	12
1.2310	35	1.0923	14	1.082	15
1.2709	40	1.1063	16	1.112	20
1.3100	45	1.1208	18	1.143	25
1.3522	50	1.1354	20	1.174	30
1.3986	55	1.1501	22	1.206	35
1.4451	60	1.1650	24	1.239	40

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## SPECIFIC GRAVITY OF SODIUM CHLORIDE SOLUTIONS

Per cent., NaCl	10°C.	20°C.	Per cent., NaCl	10°C.	20°C.
1	1.00707	1.00534	14	1.10491	1.10085
2	1.01442	1.01246	16	1.12056	1.11621
4	1.02920	1.02680	18	1.13643	1.13190
6	1.04408	1.04127	20	1.15254	1.14779
8	1.05907	1.05589	22	1.16891	1.16395
10	1.07419	1.07068	24	1.18557	1.18040
12	1.08946	1.08566	26	1.20254	1.19717

Solution is saturated at slightly over 26 per cent. NaCl. Table reprinted from International Critical Tables, Vol. III

## DENSITY OF SUGAR SOLUTIONS AT 20°C. COMPARED TO WATER AT 4°C.<sup>1</sup>

Per cent, sugar	Sp. gr.	Per cent, sugar	Sp. gr.	Per cent., sugar	Sp. gr.
1	1.00212	15	1.05917	65	1.31633
2	1.00602	20	1.08096	70	1.34717
3	1.00993	25	1.10356	75	1.37897
4	1.01388	30	1.12698	80	1.41172
5	1.01785	35	1.15128	85	1.44539
6	1.02186	40	1.17645	90	1.47998
7	1.02589	45	1.20254	95	1.51546
8	1.02994	50	1.22957	100	1.55180
9	1.03814	55	1.25754		
10	1.03403	60	1.28646		

<sup>1</sup> Data furnished by the Bureau of Standards.



## ALCOHOL-WATER MIXTURES

Cubic centimeters abs. alcohol in 100 cc. mixture	Density of $C_2H_5OH-H_2O$ mixture to water at 15°C.	Per cent. by weight of ethyl alcohol
1	0.9984	0.80
2	0.9969	1.64
3	0.9955	2.44
4	0.9941	3.24
5	0.9928	4.04
10	0.9865	8.15
15	0.9810	12.26
20	0.9759	16.44
25	0.9708	20.45
30	0.9655	24.89
35	0.9592	29.20
40	0.9520	33.59
45	0.9436	37.97
50	0.9344	42.69
55	0.9242	47.44
60	0.9135	52.34
65	0.9022	57.39
70	0.8903	62.62
75	0.8776	68.04
80	0.8642	73.69
85	0.8498	79.59
90	0.8342	85.82
95	0.8164	92.54
100	0.7943	100.00

Alcohol		Sp. gr. 60°F.	British proof	American proof	Fiscal proof
By wt.	By vol.				
100	100	0.794	74.8	200	175.35
49.22	57	0.920	proof	114	100
42.48	50	0.934	-12	100	86.17

NOTE.—Formerly proof spirit was such that it could be poured over gun-powder and the powder would still burn, a test easily applied by smugglers and the like. See also p. 146 for other alcohol constants.

DENSITIES OF SOME SALINE AND ACID SOLUTIONS<sup>1</sup>

	Chemical comp.	Temp. °C.	Percentage of salt by weight in 100 lb. solution					
			5	10	20	30	40	60
Acid:								
Acetic.....	CH <sub>3</sub> COOH	15 0	1.0067	1.0142	1.0284	1.0412	1.0523	1.0685
Chromic.....	CrO <sub>3</sub>	15 0	1.036	1.076	1.166	1.268	1.383	1.656
Hydrobromic.....	HBr	14 0	1.033	1.072	1.157	1.255		
Hydroiodic.....	HI	13 0	1.036	1.076	1.164	1.269	1.347	
Hydrochloric.....	HCl	15 0	1.034	1.049	1.098	1.149	1.197	
Hydrofluoric.....	HF	18 0	1.017	1.039	1.086	1.115	1.151	1.239
Phosphoric.....	H <sub>3</sub> PO <sub>4</sub>	15 0	1.026	1.055	1.118	1.180	1.253	1.420
Phosphorous.....	H <sub>3</sub> PO <sub>3</sub>	15 0	1.017			1.597		
Alum.....	KAl(SO <sub>4</sub> ) <sub>2</sub> ·12H <sub>2</sub> O	17 5	1.0258	1.0323				
Ammon.-iron alum	(NH <sub>4</sub> ) <sub>2</sub> Fe(SO <sub>4</sub> ) <sub>6</sub> ·6H <sub>2</sub> O	19 0	1.030	1.060	1.124	1.193		
Ammonium chloride.....	NH <sub>4</sub> Cl	15 0	1.042					
Aluminum chloride.....	AlCl <sub>3</sub>	15 0	1.0360	1.0734	1.1537	1.2422	1.3415	
Aluminum sulphate.....	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	15 0	1.0569	1.1075	1.2074			
Ammonium acetate.....	NH <sub>4</sub> C <sub>2</sub> H <sub>3</sub> O <sub>2</sub>	15 0	1.012	1.022	1.042	1.062	1.077	
Ammonium nitrate.....	NH <sub>4</sub> NO <sub>3</sub>	15 0	1.015	1.030	1.058			
Barium chloride.....	BaCl <sub>2</sub>	17 5	1.020	1.042	1.086	1.131	1.179	1.283
Barium hydroxide.....	Ba(OH) <sub>2</sub>	18 0	1.046	1.095	1.207	1.60		
Calcium chloride.....	CaCl <sub>2</sub>	15 0	1.043	1.087	1.182	1.288	1.04330	
Cadmium sulphate.....	CdSO <sub>4</sub>	18 0	1.049	1.103	1.225	1.373		
Cobalt sulphate.....	CoSO <sub>4</sub>	15 0	1.055					
Magnesium chloride.....	MgCl <sub>2</sub>	15 0	1.042	1.086	1.178	1.279		
Magnesium sulphate.....	MgSO <sub>4</sub>	15 0	1.052	1.105	1.212			
Manganese sulphate.....	MnSO <sub>4</sub> ·4H <sub>2</sub> O	15 0	1.032	1.065	1.136	1.215	1.304	
Nickel sulphate.....	NiSO <sub>4</sub>	0 0	1.060	1.086				
Potass. alum. sulphate.....	KAlSO <sub>4</sub> ·12H <sub>2</sub> O	15 0	1.021	1.053	1.1121			
Sodium arsenate.....	Na <sub>2</sub> AsO <sub>4</sub> ·12H <sub>2</sub> O	17 0	1.021	1.053				
Potass. bichromate.....	K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	19.5	1.034	1.071				
Potass. bromide.....	KBr	19.5	1.035	1.073	1.157	1.253		
Potass. carbonate.....	K <sub>2</sub> CO <sub>3</sub>	15.0	1.044	1.092	1.192	1.300	1.417	



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## SPECIFIC GRAVITY OF ALCOHOL-WATER MIXTURES

Parts alcohol by weight	Ethyl alcohol				
	10°C.	15°C.	20°C.	40°C.	Per cent. by volume 60°F.
0	0.99973	0.99913	0.99823	0.99225	0.000
2	0.99602	0.99542	0.99453	0.98846	2.510
4	0.99258	0.99195	0.99103	0.98485	5.002
6	0.98946	0.98877	0.98780	0.98142	7.479
8	0.98660	0.98584	0.98478	0.97808	9.943
10	0.98393	0.98304	0.98187	0.97475	12.393
12	0.98145	0.98041	0.97910	0.97150	14.832
14	0.97911	0.97790	0.97643	0.96829	17.259
16	0.97692	0.97552	0.97387	0.96512	19.676
18	0.97473	0.97313	0.97129	0.96189	22.081
20	0.97252	0.97068	0.96864	0.95856	24.472
22	0.97021	0.96818	0.96592	0.95516	26.849
24	0.96787	0.96558	0.96312	0.95168	29.210
26	0.96539	0.96287	0.96020	0.94810	31.555
28	0.96268	0.95996	0.95710	0.94438	33.879
30	0.95977	0.95686	0.95382	0.94055	36.181
32	0.95655	0.95357	0.95038	0.93662	38.459
34	0.95334	0.95011	0.94678	0.93257	40.716
36	0.94986	0.94650	0.94306	0.92843	42.944
38	0.94620	0.94273	0.93919	0.92422	45.149
40	0.94238	0.93882	0.93518	0.91992	47.328
42	0.93842	0.93478	0.93107	0.91554	49.480
44	0.93433	0.93062	0.92685	0.91108	51.605
46	0.93017	0.92640	0.92257	0.90660	53.705
48	0.92593	0.92211	0.91823	0.90207	55.780
50	0.92162	0.91776	0.91384	0.89750	57.830
52	0.91723	0.91333	0.90936	0.89288	59.852
54	0.91279	0.90885	0.90485	0.88823	61.850
56	0.90831	0.90433	0.90031	0.88356	63.820
58	0.90381	0.89980	0.89574	0.87888	65.768
60	0.89927	0.89523	0.89113	0.87417	67.690
62	0.89464	0.89062	0.88650	0.86943	69.586
64	0.89006	0.88597	0.88183	0.86466	71.455
66	0.88541	0.88130	0.87713	0.85987	73.299
68	0.88074	0.87660	0.87241	0.85507	75.117
70	0.87602	0.87187	0.86766	0.85025	76.909
72	0.87127	0.86710	0.86287	0.84540	78.672
74	0.86648	0.86229	0.85806	0.84053	80.410
76	0.86168	0.85747	0.85322	0.83564	82.121
78	0.85685	0.85262	0.84835	0.83074	83.805
80	0.85197	0.84772	0.84344	0.82578	85.459
82	0.84702	0.84277	0.83848	0.82079	87.083
84	0.84203	0.83777	0.83348	0.81576	88.678
86	0.83697	0.83271	0.82840	0.81067	90.240
88	0.83181	0.82754	0.82323	0.80552	91.766
90	0.82654	0.82227	0.81797	0.80028	93.254
92	0.82114	0.81688	0.81257	0.79491	94.700
94	0.81561	0.81134	0.80705	0.78947	96.103
96	0.80991	0.80566	0.80138	0.78388	97.459
98	0.80399	0.79975	0.79547	0.77806	98.759
100	0.79784	0.79360	0.78934	0.77203	100.000

Bureau of Standards, Circ. 19.

Distilled water at 4°C. (maximum density) as 1.

# PHYSICAL CONSTANTS

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## TEMPERATURE CORRECTIONS OF ALCOHOLOMETERS<sup>1</sup> STANDARD AT 60°F.

Observed per cent alcohol	Observed temperatures, degrees Fahrenheit												
	50 +	52 +	54 +	56 +	58 +	62 -	64 -	66 -	68 -	70 -	75 -	80 -	85 -
0	0.37	0.32	0.26	0.18	0.09	0.09	0.21	0.33	0.47	0.61	0.92	1.24	
2	0.39	0.33	0.26	0.18	0.10	0.11	0.23	0.35	0.48	0.63	1.02	1.46	
4	0.42	0.35	0.28	0.19	0.10	0.12	0.25	0.38	0.52	0.67	1.08	1.54	2.05
6	0.48	0.40	0.32	0.22	0.11	0.14	0.27	0.42	0.57	0.74	1.18	1.66	2.19
8	0.56	0.47	0.36	0.25	0.13	0.16	0.31	0.47	0.64	0.81	1.28	1.80	2.37
10	0.66	0.55	0.43	0.30	0.16	0.17	0.34	0.52	0.71	0.90	1.43	1.99	2.59
12	0.81	0.68	0.52	0.36	0.18	0.20	0.39	0.59	0.80	1.02	1.58	2.20	2.84
14	0.99	0.80	0.62	0.42	0.21	0.22	0.44	0.66	0.91	1.14	1.78	2.44	3.12
16	1.19	0.96	0.74	0.49	0.24	0.26	0.52	0.77	1.03	1.31	2.02	2.72	3.43
18	1.41	1.11	0.86	0.58	0.29	0.29	0.58	0.88	1.18	1.49	2.25	3.03	3.78
20	1.62	1.31	0.99	0.67	0.34	0.32	0.66	0.98	1.33	1.65	2.48	3.34	4.17
22	1.82	1.46	1.10	0.74	0.38	0.36	0.71	1.07	1.44	1.78	2.66	3.56	4.46
24	1.98	1.58	1.20	0.80	0.40	0.38	0.77	1.16	1.54	1.91	2.84	3.78	4.75
26	2.12	1.69	1.27	0.85	0.42	0.40	0.80	1.21	1.64	2.02	3.01	4.00	5.00
28	2.24	1.78	1.34	0.89	0.44	0.42	0.86	1.30	1.72	2.12	3.21	4.19	5.23
30	2.31	1.84	1.36	0.90	0.44	0.46	0.91	1.35	1.79	2.22	3.31	4.37	5.44
32	2.32	1.86	1.39	0.92	0.46	0.46	0.91	1.36	1.81	2.26	3.36	4.48	5.57
34	2.31	1.85	1.38	0.92	0.46	0.46	0.91	1.36	1.82	2.27	3.40	4.53	5.64
36	2.28	1.82	1.37	0.91	0.46	0.46	0.92	1.37	1.82	2.27	3.41	4.54	5.67
38	2.26	1.80	1.36	0.90	0.46	0.46	0.91	1.36	1.81	2.26	3.39	4.52	5.65
40	2.24	1.79	1.34	0.89	0.45	0.45	0.90	1.34	1.79	2.24	3.36	4.48	5.61
45	2.14	1.71	1.28	0.85	0.42	0.44	0.87	1.30	1.74	2.17	3.25	4.36	5.47
50	2.04	1.64	1.23	0.81	0.40	0.42	0.84	1.25	1.66	2.09	3.14	4.25	5.36
55	1.98	1.58	1.19	0.79	0.39	0.40	0.81	1.21	1.61	2.02	3.03	4.15	5.26
60	1.90	1.52	1.14	0.76	0.39	0.39	0.78	1.17	1.55	1.95	2.93	4.03	5.14
65	1.85	1.47	1.11	0.74	0.38	0.38	0.75	1.13	1.50	1.88	2.84	3.90	5.01
70	1.78	1.42	1.08	0.72	0.36	0.36	0.72	1.09	1.45	1.82	2.74	3.84	4.95
75	1.71	1.36	1.04	0.70	0.34	0.34	0.70	1.05	1.40	1.75	2.63	3.74	4.85
80	1.63	1.30	0.98	0.66	0.32	0.34	0.68	1.00	1.33	1.68	2.53	3.64	4.75
82	1.60	1.28	0.96	0.64	0.32	0.32	0.65	0.98	1.31	1.64	2.47	3.58	4.69
84	1.56	1.24	0.94	0.62	0.30	0.32	0.64	0.96	1.28	1.60	2.41	3.52	4.64
86	1.51	1.20	0.91	0.60	0.30	0.31	0.62	0.93	1.24	1.56	2.36	3.47	4.59
88	1.46	1.16	0.88	0.58	0.29	0.31	0.60	0.90	1.20	1.51	2.28	3.38	4.50
90	1.39	1.12	0.84	0.56	0.28	0.29	0.58	0.86	1.15	1.45	2.20	3.30	4.41
92	1.32	1.06	0.82	0.53	0.26	0.27	0.54	0.82	1.09	1.51	2.09	3.22	4.32
94	1.22	0.98	0.74	0.49	0.24	0.25	0.51	0.76	1.02	1.29	1.95	2.64	3.36
96	1.12	0.90	0.68	0.45	0.23	0.23	0.46	0.70	0.94	1.19	1.86	2.46	3.11
98	0.99	0.79	0.60	0.40	0.20	0.21	0.41	0.63	0.85	1.07	1.65	2.24	2.85
100	...	...	...	...	...	0.18	0.36	0.55	0.74	0.94	1.43	1.93	2.47

Add the correction if the temperature at which observations are made is below 60°F.; subtract the correction if the temperature of observation be above 60°F.

<sup>1</sup> Bureau of Standards, *Circ.*, 19.

# 148 METALLURGISTS AND CHEMISTS' HANDBOOK

## BOILING POINTS

### BOILING POINTS OF THE METALS<sup>5</sup>

	Visible ebullition	Volatil- ization com- mences		Visible ebullition	Volatil- ization com- mences
Antimony....	1420°C. <sup>2</sup>	.....	Silicon.....	3800°C. <sup>4</sup>	1350°C. <sup>3</sup>
Chromium....	2200°C. <sup>2</sup>	1420°C. <sup>3</sup>	Silver.....	1955°C. <sup>2</sup>	850°C.
Copper <sup>1</sup> .....	2310°C. <sup>2</sup>	960°C. <sup>3</sup>	Tantalum....	.....	2200°C. <sup>3</sup>
Gold.....	2100°C. <sup>3</sup>	970°C. <sup>1</sup>	Tin.....	2275°C. <sup>2</sup>	880°C. <sup>3</sup>
Manganese....	1900°C. <sup>2</sup>	1290°C. <sup>3</sup>	Thallium....	1280°C. (?)	.....
			Wolfram.....	3700°C. <sup>4</sup>	2450°C. <sup>3</sup>

<sup>1</sup> According to TIEDE and BIRNBAUER, copper boils at 2000°.

<sup>2</sup> According to H. C. GREENWOOD.

<sup>3</sup> According to TIEDE and BIRNBAUER, *Zeit. anorg. chem.*, 1914, p. 129.

<sup>4</sup> WATTS, *Tr. Electrochem. Soc.*, 1907, p. 141.

<sup>5</sup> For further data see pp. 302 and 303.

	Beginning of evaporation <i>in vacuo</i> <sup>1</sup>	Boiling point <i>in vacuo</i> <sup>1</sup>	Boiling-point 760° mm. <sup>1</sup>
Bismuth.....	270°C.	993°C.	1440°C.
Cadmium.....	156	450	749
Mercury.....	-40	155	357
Potassium.....	63	365	667
Silver.....	680	1360	1955
Sodium.....	98	418	742
Zinc.....	184	550	920
Sulphur.....	.....	.....	444.5

<sup>1</sup> According to H. C. GREENWOOD.

### BOILING POINTS OF SOME COMMON COMPOUNDS

Ammonia.....	- 29°F.
Camphor (C <sub>10</sub> H <sub>16</sub> O).....	408.4°F.
Carbon dioxide.....	- 112°F.
Carbon disulphide.....	115.3°F.
Ethylene bromide.....	320.0°F.
Sulphur dioxide.....	+ 14°F.

**BOILING POINTS OF NITRIC ACID SOLUTIONS IN WATER<sup>1</sup>**  
(160 mm. pressure)

Per cent., HNO <sub>3</sub>	Boiling point, degrees C.	Per cent., HNO <sub>3</sub>	Boiling point, degrees C.
19.37	103.56	67.74	121.67
30.43	108.08	68.18	121.79
41.38	112.59	69.24	121.80
51.63	116.85	71.10	121.80
56.01	118.88	73.56	120.75
59.77	120.06	80.50	115.45
63.89	121.27	85.51	108.12
65.17	121.66	90.06	102.03
.....	.....	95.45	95.42

<sup>1</sup> CREIGHTON and GITHENS, "Journal of the Franklin Institute," February, 1915.

A solution containing 20.24 per cent. of HCl by weight boils unchanged at 110°C., i.e., at a lower concentration the solution will grow stronger on boiling; at a higher concentration it will grow weaker; at this concentration vapor and liquid are in equilibrium at 760 mm. pressure.

## EQUIVALENT EVAPORATION FROM AND AT 212 DEGREES

Temperature of feed water, degrees F.	Pressure of steam in pounds absolute—dry saturated												Temperature of feed water, degrees F.
	15	25	35	45	55	65	75	85	95	105	115	125	
32	1.1858	1.1958	1.2024	1.2073	1.2112	1.2144	1.2171	1.2195	1.2216	1.2234	1.2251	1.2266	32
35	1.1827	1.1927	1.1993	1.2042	1.2081	1.2113	1.2140	1.2164	1.2184	1.2203	1.2219	1.2235	35
40	1.1775	1.1875	1.1911	1.1990	1.2030	1.2062	1.2088	1.2112	1.2133	1.2151	1.2168	1.2183	40
45	1.1723	1.1823	1.1859	1.1939	1.1978	1.2010	1.2037	1.2060	1.2081	1.2099	1.2116	1.2131	45
50	1.1672	1.1772	1.1838	1.1887	1.1926	1.1958	1.1985	1.2009	1.2029	1.2048	1.2064	1.2080	50
55	1.1620	1.1720	1.1786	1.1836	1.1875	1.1907	1.1933	1.1957	1.1978	1.1996	1.2013	1.2028	55
60	1.1569	1.1669	1.1735	1.1784	1.1823	1.1855	1.1882	1.1906	1.1926	1.1945	1.1961	1.1977	60
65	1.1517	1.1617	1.1683	1.1733	1.1772	1.1804	1.1830	1.1854	1.1875	1.1893	1.1910	1.1925	65
70	1.1466	1.1566	1.1632	1.1681	1.1720	1.1752	1.1779	1.1803	1.1823	1.1842	1.1858	1.1874	70
75	1.1414	1.1514	1.1580	1.1630	1.1669	1.1701	1.1728	1.1751	1.1772	1.1790	1.1807	1.1823	75
80	1.1363	1.1463	1.1529	1.1578	1.1618	1.1650	1.1676	1.1700	1.1721	1.1739	1.1756	1.1771	80
85	1.1312	1.1412	1.1478	1.1527	1.1566	1.1598	1.1625	1.1649	1.1669	1.1688	1.1704	1.1720	85
90	1.1260	1.1360	1.1426	1.1476	1.1515	1.1547	1.1574	1.1597	1.1618	1.1636	1.1653	1.1668	90
95	1.1209	1.1309	1.1375	1.1424	1.1463	1.1495	1.1522	1.1546	1.1566	1.1585	1.1602	1.1617	95
100	1.1158	1.1258	1.1323	1.1373	1.1412	1.1444	1.1471	1.1495	1.1515	1.1534	1.1550	1.1566	100
105	1.1106	1.1206	1.1272	1.1322	1.1361	1.1393	1.1420	1.1443	1.1464	1.1482	1.1499	1.1516	105
110	1.1055	1.1155	1.1221	1.1270	1.1309	1.1341	1.1368	1.1391	1.1412	1.1431	1.1447	1.1463	110
115	1.1004	1.1103	1.1169	1.1219	1.1258	1.1290	1.1318	1.1341	1.1361	1.1380	1.1396	1.1412	115
120	1.0952	1.1052	1.1118	1.1167	1.1207	1.1239	1.1265	1.1289	1.1310	1.1328	1.1345	1.1360	120
125	1.0901	1.1001	1.1067	1.1116	1.1155	1.1187	1.1214	1.1238	1.1258	1.1277	1.1293	1.1309	125
130	1.0849	1.0949	1.1015	1.1065	1.1104	1.1136	1.1163	1.1186	1.1207	1.1225	1.1242	1.1257	130
135	1.0798	1.0898	1.0964	1.1013	1.1052	1.1084	1.1111	1.1135	1.1155	1.1174	1.1190	1.1206	135
140	1.0746	1.0846	1.0912	1.0962	1.1001	1.1033	1.1060	1.1083	1.1104	1.1123	1.1139	1.1154	140
145	1.0695	1.0795	1.0861	1.0911	1.0950	1.0981	1.1008	1.1032	1.1053	1.1071	1.1088	1.1103	145
150	1.0643	1.0743	1.0809	1.0859	1.0898	1.0930	1.0957	1.0981	1.1001	1.1020	1.1036	1.1052	150
155	1.0592	1.0692	1.0758	1.0807	1.0846	1.0878	1.0905	1.0929	1.0950	1.0968	1.0985	1.1000	155
160	1.0540	1.0640	1.0706	1.0756	1.0795	1.0827	1.0854	1.0877	1.0898	1.0917	1.0933	1.0948	160



165	1.0459	1.0389	1.0655	1.0704	1.0743	1.0775	1.0802	1.0826	1.0846	1.0865	1.0881	1.0897	165
170	1.0437	1.0537	1.0603	1.0653	1.0692	1.0724	1.0751	1.0774	1.0795	1.0813	1.0830	1.0845	170
171	1.0427	1.0527	1.0593	1.0642	1.0681	1.0713	1.0740	1.0764	1.0785	1.0803	1.0820	1.0835	171
172	1.0417	1.0517	1.0583	1.0632	1.0671	1.0703	1.0730	1.0754	1.0774	1.0793	1.0809	1.0825	172
173	1.0406	1.0506	1.0572	1.0622	1.0661	1.0693	1.0720	1.0743	1.0764	1.0782	1.0799	1.0814	173
174	1.0396	1.0496	1.0562	1.0611	1.0651	1.0683	1.0709	1.0731	1.0754	1.0772	1.0789	1.0804	174
175	1.0386	1.0486	1.0552	1.0601	1.0640	1.0672	1.0699	1.0723	1.0743	1.0762	1.0778	1.0793	175
176	1.0375	1.0475	1.0541	1.0591	1.0630	1.0662	1.0689	1.0712	1.0733	1.0752	1.0768	1.0783	176
177	1.0365	1.0465	1.0531	1.0580	1.0620	1.0651	1.0678	1.0702	1.0723	1.0741	1.0758	1.0773	177
178	1.0355	1.0455	1.0521	1.0570	1.0610	1.0641	1.0668	1.0692	1.0712	1.0731	1.0747	1.0763	178
179	1.0344	1.0444	1.0510	1.0560	1.0599	1.0631	1.0658	1.0681	1.0702	1.0721	1.0737	1.0752	179
180	1.0334	1.0434	1.0500	1.0549	1.0589	1.0621	1.0647	1.0671	1.0692	1.0710	1.0727	1.0742	180
181	1.0324	1.0424	1.0490	1.0539	1.0578	1.0610	1.0637	1.0661	1.0681	1.0700	1.0716	1.0732	181
182	1.0313	1.0413	1.0479	1.0529	1.0568	1.0600	1.0627	1.0650	1.0671	1.0690	1.0706	1.0721	182
183	1.0303	1.0403	1.0469	1.0518	1.0558	1.0590	1.0616	1.0640	1.0661	1.0679	1.0696	1.0711	183
184	1.0293	1.0393	1.0459	1.0508	1.0547	1.0579	1.0606	1.0630	1.0650	1.0668	1.0685	1.0701	184
185	1.0282	1.0382	1.0448	1.0498	1.0537	1.0569	1.0596	1.0619	1.0640	1.0658	1.0675	1.0691	185
186	1.0272	1.0372	1.0438	1.0488	1.0527	1.0559	1.0585	1.0609	1.0630	1.0648	1.0665	1.0680	186
187	1.0262	1.0362	1.0428	1.0477	1.0516	1.0548	1.0575	1.0599	1.0619	1.0638	1.0654	1.0670	187
188	1.0251	1.0351	1.0417	1.0467	1.0506	1.0538	1.0565	1.0588	1.0609	1.0628	1.0644	1.0660	188
189	1.0241	1.0341	1.0407	1.0457	1.0496	1.0528	1.0554	1.0578	1.0599	1.0617	1.0634	1.0649	189
190	1.0231	1.0331	1.0397	1.0446	1.0485	1.0517	1.0544	1.0568	1.0588	1.0607	1.0623	1.0639	190
191	1.0220	1.0320	1.0386	1.0436	1.0475	1.0507	1.0534	1.0557	1.0578	1.0597	1.0613	1.0629	191
192	1.0210	1.0310	1.0376	1.0425	1.0465	1.0497	1.0523	1.0547	1.0568	1.0586	1.0603	1.0618	192
193	1.0200	1.0300	1.0366	1.0415	1.0454	1.0486	1.0513	1.0537	1.0557	1.0576	1.0592	1.0608	193
194	1.0189	1.0289	1.0355	1.0405	1.0444	1.0476	1.0503	1.0526	1.0547	1.0566	1.0582	1.0597	194
195	1.0179	1.0279	1.0345	1.0395	1.0434	1.0466	1.0493	1.0516	1.0537	1.0555	1.0572	1.0587	195
196	1.0169	1.0269	1.0335	1.0384	1.0423	1.0455	1.0482	1.0506	1.0526	1.0545	1.0561	1.0577	196
197	1.0158	1.0258	1.0324	1.0374	1.0413	1.0445	1.0472	1.0495	1.0516	1.0535	1.0551	1.0566	197
198	1.0148	1.0248	1.0314	1.0363	1.0403	1.0435	1.0461	1.0485	1.0506	1.0524	1.0541	1.0556	198
199	1.0138	1.0238	1.0304	1.0353	1.0392	1.0424	1.0451	1.0475	1.0495	1.0514	1.0530	1.0546	199
200	1.0127	1.0227	1.0293	1.0343	1.0382	1.0414	1.0441	1.0464	1.0485	1.0504	1.0520	1.0535	200
201	1.0117	1.0217	1.0283	1.0332	1.0372	1.0404	1.0430	1.0454	1.0475	1.0493	1.0510	1.0525	201

<sup>1</sup> From "Power," Mar. 17, 1914.

EQUIVALENT EVAPORATION FROM AND AT 212 DEGREES. *Continued*

Temperature of feed water, degrees F.	Pressure of steam in pounds absolute—dry saturated												Temperature of feed water, degrees F.
	15	25	35	45	55	65	75	85	95	105	115	125	
202	1.0107	1.0207	1.0273	1.0322	1.0361	1.0393	1.0420	1.0444	1.0464	1.0483	1.0499	1.0515	202
203	1.0096	1.0196	1.0262	1.0312	1.0351	1.0383	1.0410	1.0433	1.0454	1.0472	1.0489	1.0504	203
204	1.0086	1.0186	1.0252	1.0301	1.0340	1.0372	1.0399	1.0423	1.0444	1.0462	1.0479	1.0494	204
205	1.0076	1.0176	1.0242	1.0291	1.0330	1.0362	1.0389	1.0413	1.0433	1.0452	1.0468	1.0484	205
206	1.0065	1.0165	1.0231	1.0281	1.0320	1.0352	1.0379	1.0402	1.0423	1.0441	1.0458	1.0473	206
207	1.0055	1.0155	1.0221	1.0270	1.0309	1.0341	1.0368	1.0392	1.0413	1.0431	1.0448	1.0463	207
208	1.0045	1.0144	1.0210	1.0260	1.0299	1.0331	1.0358	1.0381	1.0402	1.0421	1.0437	1.0453	208
209	1.0034	1.0134	1.0200	1.0250	1.0289	1.0321	1.0347	1.0371	1.0392	1.0410	1.0427	1.0442	209
210	1.0024	1.0124	1.0190	1.0239	1.0278	1.0310	1.0337	1.0361	1.0381	1.0400	1.0416	1.0432	210
212	1.0003	1.0103	1.0169	1.0218	1.0258	1.0290	1.0316	1.0340	1.0361	1.0379	1.0396	1.0411	212
215	0.9972	1.0072	1.0138	1.0188	1.0227	1.0259	1.0285	1.0309	1.0330	1.0348	1.0365	1.0380	215
220	0.9920	1.0020	1.0086	1.0135	1.0174	1.0206	1.0233	1.0257	1.0277	1.0296	1.0312	1.0328	220
225	0.9868	0.9968	1.0034	1.0083	1.0123	1.0155	1.0181	1.0205	1.0226	1.0244	1.0261	1.0276	225
230	0.9816	0.9916	0.9981	1.0031	1.0070	1.0102	1.0129	1.0153	1.0173	1.0192	1.0208	1.0224	230
235	0.9764	0.9864	0.9930	0.9979	1.0019	1.0050	1.0077	1.0101	1.0123	1.0140	1.0157	1.0172	235
240	0.9711	0.9811	0.9877	0.9927	0.9966	0.9998	1.0025	1.0048	1.0069	1.0088	1.0104	1.0120	240
245	0.9660	0.9760	0.9825	0.9874	0.9913	0.9945	0.9972	0.9996	1.0016	1.0035	1.0052	1.0067	245
250	0.9606	0.9706	0.9772	0.9822	0.9861	0.9893	0.9920	0.9943	0.9964	0.9982	0.9999	1.0014	250
255	0.9553	0.9653	0.9721	0.9770	0.9809	0.9841	0.9868	0.9892	0.9912	0.9931	0.9947	0.9963	255
260	0.9502	0.9602	0.9668	0.9718	0.9757	0.9789	0.9816	0.9839	0.9860	0.9878	0.9895	0.9910	260
265	0.9450	0.9550	0.9616	0.9665	0.9704	0.9736	0.9763	0.9787	0.9807	0.9826	0.9842	0.9858	265
270	0.9397	0.9497	0.9563	0.9613	0.9652	0.9684	0.9710	0.9734	0.9755	0.9773	0.9790	0.9805	270
275	0.9345	0.9445	0.9511	0.9560	0.9599	0.9631	0.9658	0.9682	0.9702	0.9721	0.9737	0.9754	275
280	0.9292	0.9392	0.9458	0.9507	0.9547	0.9579	0.9605	0.9629	0.9650	0.9668	0.9685	0.9700	280
285	0.9238	0.9338	0.9404	0.9454	0.9493	0.9525	0.9552	0.9575	0.9596	0.9615	0.9631	0.9647	285
290	0.9186	0.9286	0.9352	0.9401	0.9440	0.9472	0.9499	0.9523	0.9543	0.9562	0.9579	0.9594	290
295	0.9133	0.9233	0.9299	0.9349	0.9388	0.9420	0.9447	0.9470	0.9491	0.9509	0.9526	0.9541	295
300	0.9080	0.9180	0.9246	0.9295	0.9334	0.9366	0.9393	0.9417	0.9437	0.9456	0.9472	0.9488	300

EQUIVALENT EVAPORATION FROM AND AT 212 DEGREES<sup>1</sup>

Temperature of feed water, degrees F.	Pressure of steam in pounds absolute—dry saturated												Temperature of feed water, degrees F.
	135	145	155	165	175	185	195	205	215	225	235	245	
32	1.2279	1.2292	1.2304	1.2315	1.2324	1.2333	1.2342	1.2351	1.2357	1.2365	1.2372	1.2378	32
35	1.2248	1.2261	1.2273	1.2283	1.2293	1.2302	1.2311	1.2319	1.2326	1.2334	1.2341	1.2347	35
40	1.2197	1.2209	1.2221	1.2232	1.2241	1.2250	1.2259	1.2268	1.2274	1.2282	1.2289	1.2295	40
45	1.2145	1.2157	1.2170	1.2180	1.2189	1.2198	1.2208	1.2216	1.2222	1.2230	1.2238	1.2244	45
50	1.2093	1.2106	1.2118	1.2128	1.2137	1.2147	1.2156	1.2164	1.2170	1.2179	1.2186	1.2192	50
55	1.2042	1.2054	1.2066	1.2077	1.2086	1.2095	1.2104	1.2113	1.2119	1.2127	1.2134	1.2141	55
60	1.1990	1.2002	1.2013	1.2025	1.2034	1.2044	1.2053	1.2061	1.2067	1.2076	1.2083	1.2089	60
65	1.1939	1.1951	1.1963	1.1974	1.1985	1.1992	1.2002	1.2010	1.2016	1.2024	1.2031	1.2038	65
70	1.1887	1.1900	1.1912	1.1922	1.1932	1.1941	1.1950	1.1958	1.1965	1.1973	1.1980	1.1986	70
75	1.1836	1.1848	1.1861	1.1871	1.1880	1.1889	1.1899	1.1907	1.1913	1.1921	1.1929	1.1935	75
80	1.1785	1.1797	1.1809	1.1820	1.1829	1.1838	1.1847	1.1856	1.1862	1.1870	1.1877	1.1883	80
85	1.1733	1.1756	1.1768	1.1778	1.1787	1.1796	1.1804	1.1810	1.1819	1.1826	1.1832	1.1838	85
90	1.1682	1.1694	1.1707	1.1717	1.1726	1.1735	1.1745	1.1753	1.1759	1.1767	1.1775	1.1781	90
95	1.1630	1.1643	1.1655	1.1665	1.1675	1.1684	1.1693	1.1701	1.1708	1.1716	1.1723	1.1729	95
100	1.1579	1.1591	1.1604	1.1614	1.1623	1.1633	1.1642	1.1650	1.1657	1.1665	1.1672	1.1678	100
105	1.1528	1.1540	1.1552	1.1563	1.1572	1.1581	1.1591	1.1599	1.1606	1.1613	1.1620	1.1627	105
110	1.1476	1.1489	1.1501	1.1511	1.1521	1.1530	1.1539	1.1547	1.1553	1.1562	1.1569	1.1575	110
115	1.1425	1.1437	1.1450	1.1460	1.1469	1.1479	1.1488	1.1496	1.1503	1.1511	1.1518	1.1524	115
120	1.1374	1.1386	1.1398	1.1409	1.1418	1.1427	1.1436	1.1445	1.1452	1.1459	1.1466	1.1472	120
125	1.1322	1.1335	1.1347	1.1357	1.1366	1.1376	1.1385	1.1393	1.1400	1.1408	1.1415	1.1421	125
130	1.1271	1.1283	1.1295	1.1306	1.1315	1.1324	1.1334	1.1342	1.1349	1.1356	1.1363	1.1370	130
135	1.1219	1.1232	1.1244	1.1254	1.1264	1.1273	1.1282	1.1290	1.1298	1.1305	1.1312	1.1318	135
140	1.1168	1.1180	1.1193	1.1203	1.1212	1.1221	1.1231	1.1239	1.1246	1.1253	1.1261	1.1267	140
145	1.1116	1.1129	1.1141	1.1151	1.1161	1.1170	1.1179	1.1188	1.1195	1.1202	1.1209	1.1215	145
150	1.1065	1.1077	1.1090	1.1100	1.1109	1.1119	1.1128	1.1136	1.1143	1.1150	1.1158	1.1164	150
155	1.1013	1.1026	1.1038	1.1048	1.1058	1.1067	1.1076	1.1085	1.1092	1.1099	1.1106	1.1112	155
160	1.0962	1.0974	1.0987	1.0997	1.1006	1.1015	1.1025	1.1033	1.1040	1.1047	1.1055	1.1061	160

<sup>1</sup> From "Power," Mar. 17, 1914.

EQUIVALENT EVAPORATION FROM AND AT 212 DEGREES. *Continued*

Temperature of feed water, degrees F.	Pressure of steam in pounds absolute—dry saturated												Temperature of feed water, degrees F.
	135	145	155	165	175	185	195	205	215	225	235	245	
165	1.0910	1.0923	1.0935	1.0945	1.0955	1.0964	1.0973	1.0981	1.0989	1.0996	1.1003	1.1009	165
170	1.0859	1.0871	1.0883	1.0894	1.0903	1.0912	1.0921	1.0930	1.0937	1.0944	1.0951	1.0958	170
171	1.0848	1.0861	1.0873	1.0883	1.0893	1.0902	1.0911	1.0920	1.0927	1.0934	1.0941	1.0947	171
172	1.0838	1.0850	1.0863	1.0873	1.0882	1.0892	1.0901	1.0909	1.0916	1.0924	1.0931	1.0937	172
173	1.0828	1.0840	1.0853	1.0863	1.0872	1.0881	1.0891	1.0899	1.0906	1.0913	1.0921	1.0927	173
174	1.0817	1.0830	1.0842	1.0853	1.0862	1.0871	1.0880	1.0889	1.0896	1.0903	1.0910	1.0916	174
175	1.0807	1.0820	1.0832	1.0842	1.0852	1.0861	1.0870	1.0878	1.0886	1.0893	1.0900	1.0906	175
176	1.0797	1.0809	1.0822	1.0832	1.0841	1.0850	1.0860	1.0868	1.0875	1.0882	1.0890	1.0896	176
177	1.0786	1.0799	1.0811	1.0822	1.0831	1.0840	1.0849	1.0858	1.0865	1.0872	1.0879	1.0885	177
178	1.0776	1.0789	1.0801	1.0811	1.0820	1.0830	1.0839	1.0847	1.0854	1.0862	1.0869	1.0875	178
179	1.0766	1.0777	1.0791	1.0801	1.0810	1.0819	1.0829	1.0837	1.0844	1.0851	1.0859	1.0865	179
180	1.0756	1.0768	1.0780	1.0791	1.0800	1.0809	1.0818	1.0827	1.0834	1.0841	1.0848	1.0854	180
181	1.0745	1.0758	1.0770	1.0780	1.0790	1.0799	1.0808	1.0816	1.0824	1.0831	1.0838	1.0844	181
182	1.0735	1.0747	1.0760	1.0770	1.0779	1.0788	1.0798	1.0806	1.0813	1.0820	1.0828	1.0834	182
183	1.0725	1.0737	1.0749	1.0760	1.0769	1.0778	1.0787	1.0796	1.0803	1.0810	1.0817	1.0823	183
184	1.0714	1.0727	1.0739	1.0749	1.0759	1.0768	1.0777	1.0785	1.0793	1.0800	1.0807	1.0813	184
185	1.0704	1.0716	1.0729	1.0739	1.0748	1.0758	1.0767	1.0775	1.0782	1.0789	1.0797	1.0803	185
186	1.0694	1.0706	1.0718	1.0729	1.0738	1.0747	1.0756	1.0765	1.0772	1.0779	1.0786	1.0793	186
187	1.0683	1.0696	1.0708	1.0718	1.0728	1.0737	1.0746	1.0754	1.0762	1.0769	1.0776	1.0782	187
188	1.0673	1.0685	1.0698	1.0708	1.0717	1.0727	1.0736	1.0744	1.0751	1.0758	1.0766	1.0772	188
189	1.0663	1.0675	1.0687	1.0698	1.0707	1.0716	1.0725	1.0734	1.0741	1.0748	1.0755	1.0762	189
190	1.0652	1.0665	1.0677	1.0687	1.0697	1.0708	1.0715	1.0723	1.0731	1.0738	1.0745	1.0751	190
191	1.0642	1.0654	1.0667	1.0677	1.0686	1.0695	1.0705	1.0713	1.0720	1.0727	1.0735	1.0741	191
192	1.0632	1.0644	1.0656	1.0667	1.0676	1.0685	1.0694	1.0703	1.0710	1.0717	1.0724	1.0731	192
193	1.0621	1.0634	1.0646	1.0656	1.0666	1.0675	1.0684	1.0692	1.0700	1.0707	1.0714	1.0720	193
194	1.0611	1.0623	1.0636	1.0646	1.0655	1.0664	1.0674	1.0682	1.0689	1.0696	1.0704	1.0710	194
195	1.0601	1.0613	1.0625	1.0636	1.0645	1.0654	1.0663	1.0672	1.0679	1.0686	1.0693	1.0700	195

196	1.0590	1.0603	1.0615	1.0625	1.0635	1.0644	1.0653	1.0661	1.0669	1.0676	1.0683	1.0689	196
197	1.0580	1.0592	1.0605	1.0615	1.0624	1.0633	1.0643	1.0651	1.0658	1.0665	1.0673	1.0679	197
198	1.0570	1.0582	1.0594	1.0605	1.0614	1.0623	1.0632	1.0641	1.0648	1.0655	1.0662	1.0668	198
199	1.0559	1.0572	1.0584	1.0594	1.0603	1.0612	1.0622	1.0630	1.0637	1.0645	1.0652	1.0658	199
200	1.0549	1.0561	1.0574	1.0583	1.0593	1.0602	1.0612	1.0620	1.0627	1.0634	1.0642	1.0648	200
201	1.0538	1.0551	1.0563	1.0574	1.0584	1.0592	1.0601	1.0610	1.0617	1.0624	1.0631	1.0637	201
202	1.0528	1.0541	1.0553	1.0563	1.0572	1.0582	1.0591	1.0599	1.0606	1.0614	1.0621	1.0627	202
203	1.0518	1.0530	1.0543	1.0553	1.0562	1.0571	1.0581	1.0589	1.0596	1.0603	1.0611	1.0617	203
204	1.0507	1.0520	1.0532	1.0542	1.0552	1.0561	1.0570	1.0579	1.0586	1.0593	1.0600	1.0606	204
205	1.0497	1.0509	1.0522	1.0532	1.0541	1.0551	1.0560	1.0568	1.0575	1.0583	1.0590	1.0596	205
206	1.0487	1.0499	1.0511	1.0522	1.0531	1.0540	1.0550	1.0558	1.0565	1.0572	1.0579	1.0586	206
207	1.0476	1.0489	1.0501	1.0511	1.0521	1.0530	1.0539	1.0548	1.0555	1.0562	1.0569	1.0575	207
208	1.0466	1.0478	1.0491	1.0501	1.0510	1.0520	1.0529	1.0537	1.0544	1.0552	1.0559	1.0565	208
209	1.0456	1.0468	1.0480	1.0491	1.0500	1.0509	1.0519	1.0527	1.0534	1.0541	1.0548	1.0555	209
210	1.0445	1.0458	1.0470	1.0480	1.0490	1.0499	1.0508	1.0516	1.0524	1.0531	1.0538	1.0544	210
212	1.0425	1.0437	1.0449	1.0460	1.0469	1.0478	1.0487	1.0496	1.0503	1.0510	1.0517	1.0523	212
215	1.0394	1.0406	1.0418	1.0429	1.0438	1.0447	1.0457	1.0465	1.0472	1.0479	1.0486	1.0493	215
220	1.0341	1.0357	1.0366	1.0376	1.0385	1.0395	1.0404	1.0412	1.0419	1.0427	1.0434	1.0440	220
225	1.0290	1.0314	1.0325	1.0334	1.0343	1.0352	1.0361	1.0368	1.0375	1.0382	1.0388	1.0394	225
230	1.0237	1.0249	1.0262	1.0272	1.0281	1.0291	1.0300	1.0308	1.0315	1.0323	1.0330	1.0336	230
235	1.0185	1.0198	1.0210	1.0221	1.0230	1.0239	1.0248	1.0257	1.0264	1.0271	1.0278	1.0284	235
240	1.0133	1.0145	1.0158	1.0168	1.0177	1.0187	1.0196	1.0204	1.0211	1.0218	1.0226	1.0232	240
245	1.0080	1.0093	1.0105	1.0115	1.0125	1.0134	1.0143	1.0151	1.0159	1.0166	1.0173	1.0179	245
250	1.0028	1.0040	1.0053	1.0063	1.0072	1.0081	1.0091	1.0099	1.0106	1.0113	1.0121	1.0127	250
255	0.9976	0.9989	1.0001	1.0011	1.0021	1.0030	1.0039	1.0047	1.0055	1.0062	1.0069	1.0075	255
260	0.9924	0.9936	0.9948	0.9959	0.9968	0.9977	0.9987	0.9995	1.0002	1.0009	1.0016	1.0023	260
265	0.9871	0.9882	0.9896	0.9906	0.9915	0.9925	0.9934	0.9942	0.9950	0.9957	0.9964	0.9970	265
270	0.9819	0.9831	0.9843	0.9854	0.9863	0.9872	0.9881	0.9890	0.9897	0.9904	0.9911	0.9918	270
275	0.9766	0.9778	0.9791	0.9801	0.9810	0.9820	0.9829	0.9837	0.9844	0.9852	0.9859	0.9865	275
280	0.9714	0.9726	0.9738	0.9749	0.9758	0.9767	0.9776	0.9785	0.9792	0.9799	0.9806	0.9812	280
285	0.9660	0.9672	0.9685	0.9695	0.9704	0.9714	0.9723	0.9731	0.9738	0.9745	0.9753	0.9759	285
290	0.9607	0.9620	0.9632	0.9642	0.9652	0.9661	0.9670	0.9678	0.9686	0.9693	0.9700	0.9706	290
295	0.9555	0.9567	0.9580	0.9590	0.9599	0.9608	0.9618	0.9626	0.9633	0.9640	0.9648	0.9654	295
300	0.9501	0.9514	0.9526	0.9536	0.9546	0.9555	0.9564	0.9572	0.9580	0.9587	0.9594	0.9600	300

## BOILING POINT OF WATER UNDER VARIOUS BAROMETRIC PRESSURES

Pressure mm. of mercury	0	1	2	3	4	5	6	7	8	9
	°C.									
680	96.91	96.95	97.00	97.03	97.07	97.11	97.15	97.20	97.24	97.28
690	97.32	97.36	97.40	97.44	97.48	97.52	97.56	97.59	97.63	97.67
700	97.71	97.75	97.79	97.83	97.87	97.91	97.95	97.99	98.03	98.07
710	98.11	98.14	98.18	98.22	98.26	98.30	98.34	98.38	98.42	98.45
720	98.49	98.53	98.57	98.61	98.65	98.69	98.72	98.76	98.80	98.84
730	98.88	98.91	98.95	98.99	99.03	99.07	99.10	99.14	99.18	99.22
740	99.25	99.29	99.33	99.37	99.41	99.44	99.48	99.52	99.56	99.59
750	99.63	99.67	99.70	99.74	99.78	99.81	99.85	99.89	99.93	99.96
760	100.00	100.03	100.07	100.11	100.15	100.18	100.22	100.26	100.29	100.33
770	100.37	100.40	100.44	100.47	100.51	100.55	100.58	100.62	100.66	100.69
780	100.73	100.76	100.80	100.84	100.87	100.91	100.94	100.98	101.01	101.05

## The Thermal Properties of Steam

Probably the most critical investigation yet made of the thermal properties of steam was that of G. A. Goodenough of the University of Illinois, from whose work the following formulas are taken:

The relation found between the pressure temperature of the steam is as follows:

$$\log p = 10.5688080 - \frac{4876.643}{T} - 0.0155 \log T \\ - 0.00406258T + 0.00000400555T^2 \\ - 0.00002 \left\{ 10 - 10 \left( \frac{t - 370}{100} \right)^2 + \left[ \frac{t - 370}{100} \right] \right\}$$

where  $p$  is the pressure in pounds per square inch, and  $T$  the absolute temperature in Fahrenheit units, while  $t$  is the temperature in Fahrenheit degrees. The absolute zero is taken as  $-459.6^\circ\text{F}$ . For the specific volume of the steam Professor Goodenough gives the expression:

$$v = 0.017 = 0.59465 \frac{T}{p} - (1 + 0.05129p^{1/2}) \frac{C_1}{T^4}$$

where  $v$  denotes the volume in cubic feet per pound, and  $\log C_1 = 10.82500$ . The "heat content" of steam at different temperatures and pressures is:

$$i = 0.320T + 0.000063T^2 - \frac{23583}{T} \\ - \frac{C_2 p (1 + 0.0342p^{1/2})}{T^4} + 0.00333p + 948.7$$

where

$$\log C_2 = 10.79155$$

The entropy of superheated steam is given by the relation

$$s = 0.73683 \log T + 0.000126T - \frac{11.7915}{T^2} \\ - 0.25355 \log p - \frac{C_p(1 + 0.0342p)}{T^5} - 0.08085$$

where

$$\log C_4 = 10.69464$$

The thermal properties of steam at very high pressures and temperatures are stated to be as follows:

Temperature, degrees F.	Pressure, lb. per sq. in.	Volume of 1 lb., cu. ft.	Weight of 1 cu. ft., lb.	Heat content of		Latent heat, B.t.u.
				Liquid, B.t.u.	Vapor, B.t.u.	
600.0	1540.4	0.272	3.68	604.5	1164	560
620.0	1658.7	0.241	4.15	633.0	1151	518
640.0	2056.6	0.187	5.35	663.0	1136	473
660.0	2360.8	0.151	6.63	700.0	1112	412
680.0	2699.1	0.118	9.86	745.0	1080	335
700.0	3074.5	0.080	12.46	823.0	1016	193
706.3	3200.0	0.048	20.92	921.0	921	0

The temperature of steam in contact with water depends upon the pressure under which it is generated. At ordinary atmospheric pressure (14.7 lb. per square inch) the temperature is 212°F., but as the pressure increases the temperature of both the steam and the water also increases.

Saturated steam is steam of the temperature due to its pressure, while superheated steam is steam heated to a temperature above that due to its pressure. Saturated steam cannot be cooled except by lowering its pressure. Steam in contact with water cannot be heated above the temperature due to its pressure.

The latent heat or heat of vaporization is obtained by subtracting from the total heat at any given temperature the heat of the liquid. Since the "total heat" is greater as the pressure increases, it will take more heat, and consequently more fuel, to make a pound of steam as the pressure increases.

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TABLE OF PROPERTIES OF SATURATED STEAM<sup>1</sup>

Pressure in pounds per square inch	Temperature, Fahrenheit	Total heat in heat units above 32°F.		Heat of vaporization of latent heat ( <i>L</i> ) in heat units $L = H - h$	Density or weight in pounds of 1 cu. ft.	Volume in cubic feet of 1 lb.	Factor of equivalent evaporation at 212°F.
		In the steam ( <i>H</i> )	In the water ( <i>h</i> )				
1	101.99	1113.1	70.0	1043.0	0.00299	334.5	0.9661
2	126.27	1120.5	94.4	1026.1	0.00576	173.6	0.9738
3	141.62	1125.1	109.8	1015.3	0.00844	118.5	0.9786
4	153.09	1128.6	121.4	1007.2	0.01107	90.33	0.9822
5	162.34	1131.5	130.7	1000.8	0.01366	73.21	0.9852
6	170.14	1133.8	138.6	995.2	0.01622	61.65	0.9876
7	176.90	1135.9	145.4	990.5	0.01874	53.39	0.9897
8	182.92	1137.7	151.5	986.2	0.02125	47.06	0.9916
9	188.33	1139.4	156.9	982.5	0.02374	42.12	0.9934
10	193.25	1140.9	161.9	979.0	0.02621	38.15	0.9949
15	213.03	1146.9	181.8	965.1	0.03826	26.14	1.0003
20	227.95	1151.5	196.9	954.6	0.05023	19.91	1.0051
25	240.04	1155.1	209.1	946.0	0.06199	16.13	1.0099
30	250.27	1158.3	219.4	938.9	0.07360	13.59	1.0129
35	259.19	1161.0	228.4	932.6	0.08508	11.75	1.0157
40	267.13	1163.4	236.4	927.0	0.09644	10.37	1.0182
45	274.29	1165.6	243.6	922.0	0.1077	9.285	1.0205
50	280.85	1167.6	250.2	917.4	0.1188	8.418	1.0225
55	286.89	1169.4	256.3	913.1	0.1299	7.698	1.0245
60	292.51	1171.2	261.9	909.3	0.1409	7.097	1.0263
65	297.77	1172.7	267.2	905.5	0.1519	6.583	1.0280
70	302.71	1174.3	272.2	902.1	0.1628	6.143	1.0295
75	307.38	1175.7	276.9	898.8	0.1736	5.760	1.0309
80	311.80	1177.0	281.4	895.6	0.1843	5.426	1.0323
85	316.02	1178.3	285.8	892.5	0.1951	5.126	1.0337
90	320.04	1179.6	290.0	889.6	0.2058	4.859	1.0350
95	323.89	1180.7	294.0	886.7	0.2165	4.619	1.0362
100	327.58	1181.9	297.9	884.0	0.2271	4.403	1.0374
105	331.13	1182.9	301.6	881.3	0.2378	4.205	1.0385
110	334.56	1184.0	305.2	878.8	0.2484	4.026	1.0396
115	337.86	1185.0	308.7	876.3	0.2589	3.862	1.0406
120	341.05	1186.0	312.0	874.0	0.2695	3.711	1.0416
125	344.13	1186.9	315.2	871.7	0.2800	3.571	1.0426
130	347.12	1187.8	318.4	869.4	0.2904	3.444	1.0435
140	352.85	1189.5	324.4	865.1	0.3113	3.212	1.0453
150	358.26	1191.2	330.0	861.2	0.3321	3.011	1.0470
160	363.40	1192.8	335.4	857.4	0.3530	2.833	1.0486
170	368.29	1194.3	340.5	853.8	0.3737	2.676	1.0502
180	372.97	1195.7	345.4	850.3	0.3945	2.535	1.0517
190	377.44	1197.1	350.1	847.0	0.4153	2.408	1.0531
200	381.73	1198.4	354.6	843.8	0.4359	2.294	1.0545
225	391.79	1201.4	365.1	836.3	0.4876	2.051	1.0576
250	400.99	1204.2	374.7	829.5	0.5393	1.854	1.0605
275	409.50	1206.8	383.6	823.2	0.5913	1.691	1.0632
300	417.42	1209.3	391.9	817.4	0.644	1.553	1.0657
325	424.82	1211.5	399.6	811.9	0.696	1.437	1.0680
350	431.90	1213.7	406.9	806.8	0.748	1.337	1.0703
375	438.40	1215.7	414.2	801.5	0.800	1.250	1.0724
400	445.15	1217.7	421.4	796.3	0.853	1.172	1.0745
500	466.57	1224.2	444.3	779.9	1.065	0.939	1.0812

<sup>1</sup> KENT, "Mechanical Engineer's Pocket-Book," New York, 1913, p. 836.



VAPOR TENSIONS OF VARIOUS METALS<sup>1</sup><sup>\*</sup> (As calculated by J. RICHARDS, "Metallurgical Calculations")

Vapor tension, mm. of mercury	Mercury at C.°	Lead at C.°	Silver at C.°	Gold at C.°	Cadmium at C.°	Zinc at C.°
0.0002	0	625	729	942	183	248
0.0005	10	658	766	987	200	267
0.0013	20	691	802	1031	218	286
0.0029	30	724	839	1075	233	305
0.0063	40	757	876	1120	250	324
0.013	50	790	913	1165	267	344
0.026	60	822	949	1209	283	363
0.050	70	855	986	1254	300	382
0.093	80	888	1023	1298	317	401
0.165	90	921	1059	1343	333	420
0.285	100	954	1096	1387	350	439
0.478	110	987	1133	1432	367	458
0.779	120	1020	1169	1476	383	477
1.24	130	1053	1206	1520	400	496
1.93	140	1086	1243	1565	417	516
2.93	150	1119	1280	1611	433	535
4.38	160	1151	1316	1654	450	554
6.41	170	1184	1353	1699	467	573
9.23	180 <sup>1</sup>	1217 <sup>1</sup>	1390 <sup>1</sup>	1743 <sup>1</sup>	483 <sup>1</sup>	592 <sup>1</sup>
14.84	190	1250	1427	1788	500	611
19.90	200	1283	1463	1832	517	630
26.25	210	1316	1500	1877	533	649
34.70	220	1349	1537	1921	550	668
45.35	230	1382	1574	1965	567	687
58.82	240	1415	1610	2010	584	706
75.75	250	1448	1647	2055	600	726
96.73	260	1480	1684	2099	617	745
123.0	270	1513	1720	2144	634	764
155.0	280	1546	1757	2188	650	783
195.0	290	1579	1794	2233	667	802
242.0	300	1612	1830	2277	684	821
300.0	310	1645	1867	2322	700	840
369.0	320	1678	1904	2366	717	859
451.0	330	1711	1941	2410	734	878
548.0	340	1744	1977	2455	750	897
663.0	350	1777	2014	2500	767	915
760.0	357 <sup>2</sup>	1800 <sup>2</sup>	2040 <sup>2</sup>	2530 <sup>2</sup>	780 <sup>2</sup>	930 <sup>2</sup>
Atmospheres pressure						
2.1	400	1951	2197	2722	851	1012
4.25	450	2116	2380	2945	934	1107
8.0	500	2280	2564	3167	1018	1203
13.8	550	2445	2747	3390	1101	1298
22.3	600	2609	2931	3612	1185	1394
34.0	650	2774	3114	3835	1268	1489
50.0	700	2938	3298	4057	1352	1585
72.0	750	3103	3481	4280	1435	1680
102.0	800	3267	3665	4502	1519	1776
137.5	850	3436	3848	4725	1602	1871
162.0	880	3525	3958	4858	1652	1928

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## VAPOR PRESSURES OF CERTAIN METALS

Barium 1.0 mm. at 887°C.  
 Calcium 1.0 mm. at 917°C.  
 Molybdenum  $643 \times 10^{-11}$  mm. at 1517°C.  
 Potassium 1.0 mm. at 343°C.  
 Sodium 1.0 mm. at 441°C.  
 Strontium 1.0 mm. at 899°C.  
 Tungsten 0.00114 mm. at 2727°C.

## MEAN VALUES OF THE VAPOR PRESSURE OF $\text{As}_2\text{O}_3$

Temperature	Vapor pressure	$\text{As}_2\text{O}_3$ per 1000 cu. ft. of gas	Temperature	Vapor pressure	$\text{As}_2\text{O}_3$ per 1000 cu. ft. of gas
°C.	Mm. of mercury	Pounds	°C.	Mm. of mercury	Pounds
100	0.000266	0.000386	220	2.065	3.00
120	0.00180	0.00261	240	5.96	8.71
140	0.01035	0.0150	260	15.7	23.2
160	0.0473	0.0685	280	38.5	58.6
180	0.186	0.270	300	89.1	144.0
200	0.653	0.947	.....	.....	.....

This table, from "Tech. Paper 81," U. S. Bureau of Mines, may be used as a rough basis for the calculation of arsenic in smelter gases. The vapor pressure of arsenic volatilized from flue dust at a given temperature is about half of the value in the table for that temperature. The heat of sublimation of arsenic varies from about 28,000 gram-cal. at 110°C. to about 25,000 at 290°C. per gram-molecule of arsenic (396 grams).

## VAPOR PRESSURES OF METALS\*

Pressure in mm. of Hg at Various Temperatures Centigrade

	$10^{-3}$	$10^{-2}$	$10^{-1}$	1	10	50	100	760
Aluminum ..	730	830	950	1,090	1,280	1,440	1,520	1,800
Antimony ..	640	620	720	840	990	1,130	1,200	1,440
Arsenic ..	220	260	370	360	430	490	510	610
Bismuth ..	540	620	720	840	990	1,130	1,200	1,440
Cadmium ..	220	270	330	410	500	590	630	780
Chromium ..	980	1,090	1,230	1,400	1,610	1,800	1,890	2,200
Copper ...	1,080	1,200	1,340	1,520	1,740	1,930	2,030	2,350
Iron .....	1,130	1,250	1,400	1,590	1,820	2,010	2,110	2,450
Lead .....	620	710	820	960	1,130	1,290	1,360	1,640
Magnesium ..	380	440	520	620	750	860	920	1,120
Manganesc. ..	790	890	1,020	1,170	1,360	1,530	1,610	1,900
Nickel .....	1,100	1,220	1,370	1,550	1,780	1,970	2,070	2,400
Platinum. .	1,730				1,755			
Silver .....	920	1,030	1,160	1,320	1,520	1,700	1,780	2,090
Thallium ..	500	570	660	770	910	1,030	1,090	1,300
Tin .....	1,010	1,130	1,270	1,440	1,660	1,850	1,940	2,260
Zinc .....	290	350	420	500	610	700	750	920

\* From R. S. DEAN, "Theoretical Metallurgy," J. Wiley & Sons, Inc. It is interesting to note that at 1727°C. molybdenum has a vapor pressure  $6.43 \times 10^{-10}$ ; and tungsten  $6.45 \times 10^{-11}$  mm.

CRYOHYDRATES. SALT AND ICE MIXTURES<sup>1</sup>

Name of salt	Minimum temp. attainable, °C.	Percentage an- hydrous salt in ice mixture
Calcium chloride.....	-55.0	29.8
Sodium bromide.....	-24.0	41.33
Sodium chloride.....	-22.0	23.60
Sodium nitrate.....	-17.5	40.80
Ammonium chloride.....	-15.0	19.27
Magnesium sulphate.....	-5.0	21.86

<sup>1</sup> "General Electric Review" 1915.COOLING MIXTURES OF SALT AND WATER<sup>1</sup>

	Mixed with 100 parts water	Temperature falls	
		From C.°	To C.°
Alum-crystallized.....	14	10.8°	9.0
Ammonium carbonate.....	30	15.3	3.2
chloride.....	30	13.3	-5.1
nitrate.....	60	13.6	-13.6
sulphate.....	75	13.2	6.8
sulphocyanate.....	133	13.2	-18.0
Calcium chloride crystallized.	250	10.8	-12.4
Magnesium sulphate crystallized.	85	11.1	-3.1
Potassium chloride.....	30	13.2	-3.0
iodide.....	140	10.8	-11.7
nitrate.....	16	13.2	-3.0
sulphate.....	12	14.7	-11.7
sulphocyanate.....	150	10.8	-23.7
Sodium acetate, cryst.....	85	10.7	-4.7
carbonate, cryst.....	40	10.7	1.6
chloride.....	36	12.6	10.1
hyposulphite, cryst....	110	10.7	-8.0
nitrate.....	75	13.2	-5.3
phosphate, cryst.....	14	10.8	7.1
sulphate, cryst.....	20	12.5	5.7

<sup>1</sup> CREMER and BICKNELL's "Chemical and Metallurgical Hand Book."

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## CAPILLARY CONSTANTS FOR MOLTEN METALS

These are the products of the rise (or depression) of the metal by the radius of the tube, or the rise or depression in tubes of 1 mm. radius. (a)

Metal	S. W. Smith	Quincke	Siedentopf	Grunmach	
Selenium....	.....	4.41	.....	.....	.....
Antimony....	8.65	9.90	.....	.....	.....
Bismuth....	6.91 7.53	9.76	8.755	.....	.....
Lead....	8.36 8.12	9.98	9.778	9.060	.....
Mercury....	6.72 6.73	8.234	.....	{ 7.39 6.09 }	Stöckle 6.548
Tin....	14.57 14.97	19.43	17.87	10.27	.....
Cadmium....	.....	19.8	21.25	.....	.....
Aluminum....	45.09	No values given		.....	.....
Zinc....	25.05 24.54	{ 28.6 30.6 }	.....	.....	Gradenwitz 14.5
Silver....	18.57 18.47	15.94	.....	.....	.....
Copper....	28.23 29.47	14.44	.....	.....	Heydweiller 6.90
Gold.....	11.29	{ 25.81 27.14 }	.....	.....	.....
Iron.....	.....	.....	.....	.....	.....

(a) Landolt expresses this as  $r \times h = a^2(\text{mm.}^2)$ ,  $a^2$  being the constant.

## COMPARISON OF VALUES FOR SURFACE TENSIONS OF METALS OBTAINED BY VARIOUS WORKERS

(Given by LANDOLT)<sup>1</sup>

Metal	S. W. Smith	Quincke	Siedentopf	Grunmach	Temp. Deg. C.
	Dynes per centimeter	Dynes per centimeter	Dynes per centimeter	Dynes per centimeter	
Selenium....	.....	92.5	.....	.....	.....
Antimony....	274.0	317.2	.....	.....	840- 850
Bismuth.....	346.0	464.9	429.5	.....	700- 850
Lead.....	424.5	{ 535.9 457 $\frac{\text{mg.}}{\text{mm.}}$	{ 509.5 519 $\frac{\text{mg.}}{\text{mm.}}$	{ 482 $\frac{\text{mg.}}{\text{mm.}}$	770- 780
Mercury.....	447.5	547.2	435.6	{ 491.2 405.0 352 359 }	15- 17
Tin.....	480.0	{ 681.2 598 $\frac{\text{mg.}}{\text{mm.}}$	{ 612.4 624 $\frac{\text{mg.}}{\text{mm.}}$	.....	750- 910
Aluminum....	520.0	No values recorded		.....	700- 820
Zinc....	707.5 <sup>a</sup>	{ 967.4 <sup>b</sup> 1103.7 }	.....	.....	580- 630
Cadmium....	.....	815.0	832.0	.....	.....
Silver.....	858.0	782.4	751.0	.....	980-1120
Gold.....	1018.0	581.0	612.2	.....	1120
Copper.....	1178.0	.....	.....	.....	1150
Nickel; iron <sup>2</sup>	1350.0	.....	.....	.....	.....

<sup>1</sup> SYDNEY W. SMITH, paper before the Institute of Metals, September, 1914.

<sup>a</sup> At 630°C. <sup>b</sup> At 420°C

The surface tensions of liquid metals are periodic functions of their atomic weights. In each period the surface tension decreases slightly, the metal of lowest atomic weight having the highest surface tension.

### Heat Conductivity (K)

A plate of the given substance 1 cm. thick, with parallel sides having a difference in temperature of  $1^{\circ}\text{C}.$ , conducts enough heat per square centimeter per second to heat  $K$  grams of water from  $0^{\circ}$  to  $1^{\circ}\text{C}.$  The table is one compiled from various sources. See also Hering's Thermal Resistivity Table on p. 167.

Metals	Temperature, degrees C.	K
Aluminum...	18	0.504
Aluminum...	100	0.492
Aluminum...	-160	0.514
Aluminum No. 1, commercial hard drawn...	79-193	0.47
No. 12 Aluminum alloy (Cu, 7.50)...	90-250	0.335
Aluminum bronze (Cu, 89.87%; Al, 9.09; Sn, 0.47%)	160-350	0.174
Antimony	0 to 30	0.044
Antimony...	100	0.040
Bismuth	0	0.0177
Bismuth...	100	0.0161
Bismuth...	-186	0.025
Brass, red (Zn, 9.9%)	20	0.446
Brass, red (Zn, 9.9%)	200	0.538
Brass, yellow (Zn, 30.8%)	20	0.290
Brass, yellow (Zn, 30.8%)	200	0.349
Cadmium...	0	0.02213
Cadmium...	100	0.02045
Cadmium	-160	0.239
Copper (hard drawn electrolytic)	90-210	0.88
Copper (annealed electrolytic)	90-210	0.90
Copper (cast electrolytic)	90-220	0.77
Copper (Cu, 99.44; Ni, 0.2; Fe, 0.036, As 0.231%)	100-230	0.52
Copper (phosphor bronze)	0	0.7198
Copper (phosphor bronze)	100	0.7226
German silver	31	0.081
German silver	100	0.0887
Gold...	18	0.700
Iron...	-160	0.152
Iron, wrought (1 per cent C)	18	0.144
Iron, wrought...	50	0.1772
Iron, wrought...	100	0.1567
Iron, wrought...	150	0.1447
Iron, wrought...	200	0.1357
Iron, wrought...	275	0.1240
Iron (pure)	18	0.161
Iron (Bessemer steel)	15	0.0964
Iron (puddled)	15	0.1375
Lead...	18	0.083
Lead...	100	0.076
Magnesium...	0 to 100	0.376
Mercury	0	0.01479
Mercury...	50	0.01893
Mercury...	100	0.024
Molybdenum	15	0.346

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Metals	Temperature, degrees C.	K
Monel metal...	15	0.06
Nickel.....	0	0.14
Palladium.....	18	0.17
Platinum.....	10 to 97	0.17
S.A.E. No. 10 Bearing alloy (Sn, 92.49; Cu, 3.58; Pb, 0.19; Sb, 3.74%)	50-100	0.92
S.A.E. No. 11 Bearing alloy (Sn, 86.92; Cu, 5.16; Pb, 0.12; Sb, 7.90%)	50-100	0.76
S.A.E. No. 12 Bearing alloy (Cu, 7.07; Pb, 63.94; Sb, 28.84%)	140-325	0.23
S.A.E. No. 40 Bearing alloy (Sn, 5.14; Cu, 84.93; Pb, 5.01; Zn, 4.92%)	155-340	0.142
S.A.E. No. 62 Bearing alloy (Sn, 10.55; Cu, 86.60; Pb, 0.04; Zn, 2.81%)	150-340	0.142
S.A.E. No. 64 Bearing alloy (Sn, 10.83; Cu, 79.04; Pb, 0.55; P, 0.30%)	140-320	0.109
S.A.E. No. 66 Bearing alloy (Sn, 5.56; Cu, 85.29; Pb, 8.26; Zn, 0.89%)	130-350	0.177
Silver.....	10 to 97	1.096
Steel (1 per cent. C)...	18	0.115
Tantalum.....	15	0.130
Tin.....	0 to 30	0.151
Tungsten.....	18	0.36
Wood's metal (99.05 Bi + 0.95 Sn)		0.008
Wood's metal (93.86 Bi + 6.14 Sn)		0.012
Zinc.....	0 to 30	0.303

Non-metals	Temperature, degrees C	K
Air	0	0.00057
Alumina brick.....	0-700	0.00204
Aniline, b.p. 183°C.	-160	0.000112
Asbestos paper		0.0006
Brick, alumina.	0-700	0.00204
building	15-1100	0.0018-0.0038
carborundum	150-1200	0.0032-0.027
fireclay.....	125-1220	0.0032-0.0054
firebrick dust.	20-98	0.00028
gas-retort.	100-1125	0.0038
graphite.....	300-700	0.024
magnesite..	50-1130	0.0027-0.0072
silica.....	100-1000	0.002 -0.0033
terra cotta	15-1100	0.0018-0.0038
Carbon, amorphous.....	37-163	0.028 -0.003
	170-330	0.027 -0.004
	240-523	0.020 -0.008
	100-750	0.124
	100-842	0.129
Carbon, graphite, artificial.....	100-390	0.338
	100-546	0.324
	100-720	0.306
	100-814	0.291
	30-2830	0.162
Carbon, graphite, natural		0.012
Carbon, powdered coke..	0-100	0.00044

Non-metals	Temperature, degrees C.	K
Carborundum.....	.....	0 00050
Cardboard.....	.....	0.0005
Cement.....	below 0	0.00016
Coal.....	below 0	0.00041
Concrete, cinder.....	.....	0.00081
Concrete, stone.....	.....	0.0022
Cork.....	.....	0.00013
Cotton, compressed....	below 0	0.00055
Cotton wool.....	.....	0.0004
Diatomaceous earth.....	17-98	0.00013
Earth's crust.....	.....	0.004
Felt.....	.....	0.00009
Firebrick (see Brick)	.....	.....
Flannel.....	below 0	0.000355
Fluorite.....	-190	0.093
Fluorite.....	0	0.025
Glass, crown.....	-190	0 00118
crown.....	0	0 00280
crown.....	100	0.00324
flint.....	-190	0 00081
flint.....	0	0.00170
flint.....	100	0.00181
flint.....	.....	0 0025
window.....	-160	0.00077
Glycerine.....	100	0.0045-0.0050
Granite.....	200	0.0043-0.0097
Granite.....	500	0.0040
Graphite (see Carbon)	.....	.....
Graphite brick (see Brick)	.....	.....
Graphite—retort dust ..	20-100	0.00040
Ice.....	-160	0.0066
Ice.....	0	0.0050
Iceland spar ..	-190	0.038
Iceland spar.....	0	0.0103
Infusorial earth.....	17-98	0.00013
Infusorial earth.....	20-650	0.00038
Lime.....	.....	0.00029
Limestone.....	40	0.0046-0.0057
Limestone.....	100	0.0039-0.0049
Limestone.....	350	0.0032-0.0035
Magnesite brick.....	50-1130	0.0027-0.0072
brick dust.....	20-100	0.00050
calcined granular.....	20-100	0.00045
calcined porous.....	20-100	0.00016
Marble (dolomitic).....	.....	0.0056
Mica, along cleavage.....	.....	0.0018
perp. to cleavage.....	.....	0.018
Naphthalene, m.p. 79°C. .	-160	0 0013
Naphthalene.....	0	0.00081
Naphthol, beta, m.p. 122°C	-160	0.00068
Naphthol.....	0	0.00062
Nitrophenol, m.p. 114°C	-160	0.00106
Nitrophenol.....	0	0.00065
Paper.....	.....	0.0003
Paraffin, m.p. 54°C.....	0	0.0006
Plaster of Paris.....	.....	0.0013
Porcelain.....	.....	0.0025
Quartz, perp. to axis....	-190	0.0586
perp. to axis.....	0	0.0173
perp. to axis.....	100	0.133
parallel to axis.....	0	0.0325

Non-metals	Temperature, degrees C.	K
Quartz sand.	18 98	0 00060
Quartzite flagstones		0 0044
Rock salt	0	0 0167
Rock salt	30	0 0150
Rubber, para		0 00045
Rubber, vulcanized	- 160	0 00033
vulcanized	0	0 00037
Sand, white, dry		0 00093
Sandstone.		0 0055
Sawdust		0 00012
Slag wool.		0 00019
Slate, parallel to cleavage.		0 0060
perp to cleavage		0 0034
Snow, fresh		0.00026
old		0 0012
Soil, slightly moist		0 0037
very dry		0 0037
Stoneware...	70 1000	0 0029-0 0053
Sulphur, rhombic	0	0 00070
Sulphuric acid	9 15	0 000765
Vaseline	20	0 00022
Vulcanite	0	0 00087
Water	0	0 001203
Water	10-8	0 001555
Wood (dry pine, dry walnut)		0 0004

**Flow of Heat from Solids to Air.**—E. E. SNYDER, C. S. ROBINSON AND W. K. LEWIS *Journ. Ind. Eng. Chem.*, 1916, Vol 8, pp. 515-516. According to J. W. Richards the coefficient of heat transfer from solids to air is proportional to the square root of the gas velocity while Langmuir (*Phys. Rev.*, 1912, Vol. 34, p. 401) states that it is a function of  $V^{1.5}$ . The work described was undertaken with a view to furnishing more accurate data. A known weight of air was blown at constant velocity through an electrically heated tube. The temperature of the tube was measured and the heat absorbed by the gas was calculated by subtracting from the total electric input the heat necessary to maintain the same temperature when no gas was passing through. Up to 750°F. the value of  $K$ , expressed in B. t. u. per sq. ft. of heating surface per deg. F. difference in temperature per hour, is independent of temperature and a function of velocity alone and equals  $39.6 V/(V + 3.67)$  where  $V$  is pounds of air per sec. per sq. ft. of section.



**Table of Thermal Resistivities<sup>1</sup>**  
**APPROXIMATELY IN ORDER OF RESISTIVITY**  
 (Temperature in Centigrade degrees)

	Thermal ohms <sup>1</sup>		
	Inch cube	Centi- meter cube	Refer- ence
Silver, 0°-100°	0.094	0.24	LB
Copper (electrode mean), 100°-497°	0.090	0.23	H
Copper (electrode mean), 100°-837°	0.11	0.27	H
Copper, 0°-100°, about	0.11	0.27	LB
Copper.....	0.13	0.32	LB
Copper, cast...	0.12	0.29	CJ
Copper, rolled...	0.11	0.28	CJ
Copper, rolled...	0.13	0.32	WF
Aluminum, 0°-100°	0.27	0.69	LB
Graphite, Acheson (electrode mean), 100°-390°	0.28	0.71	H
Graphite, Acheson (electrode mean), 100°-914°	0.32	0.82	H
Brass, 0°-100°	0.36	0.92	LB
Iron (electrode mean), 100°-398°	0.28	0.71	H
Iron (electrode mean), 100°-398°	0.43	1.1	H
Iron, wrought.....	0.22	0.55	CJ
Iron, wrought, 0°	0.46	1.2	LB
Iron, wrought, 275°	0.76	1.9	LB
Iron, wrought...	0.79	2.0	WF
Iron, cast.....	0.26	0.66	CJ
Iron, cast, 30°	0.63	1.6	LB
Steel.....	0.24	0.60	CJ
Steel.....	0.81	2.1	WF
Steel, various...	0.81	2.1	LB
Steel, 10 per cent manganese	3.0	7.7	LB
Platinum.....	0.25	0.63	CJ
Platinum, 18°-100°	0.55	1.4	LB
Platinum...	1.1	2.9	WF

<sup>1</sup> HERING uses an expression, the thermal ohm, which is the resistance through which 1 watt of heat flow will pass when the temperature drop is 1°C. Hence, if  $R$  is the thermal resistance in thermal ohms,  $W$  the flow of heat in watts and  $T$  the temperature in Centigrade degrees:

$$W = \frac{T}{R}$$

Or if  $r$  is the specific thermal resistance in thermal ohms per centimeter cube then

$$R = \frac{rL}{S}$$

where  $L$  is length and  $S$  is cross section.

To reduce a thermal conductivity in gram calories per second to resistivity in thermal ohms, multiply the reciprocal of the conductivity by 0.2388, when both are for 1 cm.<sup>3</sup> To reduce gram calories to watts, multiply by 4.186. In order to compare thermal resistivities Mr. HERING called that of silver the unit, and reduced all values to this base.

To use the data of the table for all purposes it may be remembered that

watts  $\times$  0.00134111 = horse power.

watts  $\times$  0.0568776 = B.t.u. per minute.

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	Thermal ohms <sup>1</sup>		
	Inch cube	Centimeter cube	Reference
Carbon (electrode mean) 100°-942°	0.72	1.9	H
Carbon (electrode mean) 100°-360°	1.05	2.7	H
Lead	0.33	0.83	CJ
Lead, 0°-100°	1.10	2.8	WP
Lead, 0°-100°	1.2	3.0	LB
Plumbago brick, about 1000°	3.8	9.6	WQ
Carborundum brick, about 1000°	4.1	10.3	WQ
Mercury, 0°-50°	5.5	14.1	LB
Quartz, 0°	5.0	15.0	LB
Graphite (probably plumbago) 7°	8.0	21.0	LB
Retort carbon, 0°	9.1	23.0	LB
Magnesia brick, about 1000°	13.0	34.0	WQ
Stone, calcareous, fine	16.0	42.0	P
Chromite brick, about 1000°	16.0	42.0	WQ
Ice	16.0	42.0	LB
Marble, fine grained, gray	9.8	25.0	P
Marble, coarse grained, white	12.0	31.0	P
Marble, 30°	19.0	48.0	LB
Stone, calcareous, ordinary	20.0	51.0	P
Firebrick, probably room temperature	21.0	53.0	D
Firebrick, about 1000°	22.0	57.0	WQ
Firebrick, mean for 500°-1300°	23.0	57.0	Z
Firebrick, mean for 0°-1300°	30.0	77.0	Z
Firebrick, about 400°-800°	44.0	112.0	CE
Firebrick, mean for 0°-500°	67.0	171.0	Z
Checker brick, about 1000°	24.0	61.0	WQ
Gas retort brick, about 1000°	25.0	63.0	WQ
Slate, 94°	26.0	67.0	LB
Building brick, about 1000°	20.0	72.0	WQ
Glass pot, about 1000°	35.0	89.0	WQ
Porcelain, 95°	38.0	96.0	LB
Terracotta, about 1000°	41.0	104.0	WQ
Chalk, solid	43.0	109.0	LB
Cement, Portland, neat, 35°	44.0	110.0	N
Cement, Portland, 90°	132.0	336.0	LB
Lava	47.0	120.0	LB
Silica brick, about 1000°	47.0	120.0	WQ
Kieselguhr brick, about 1000°	52.0	133.0	WQ
Red brick wall, average 8-in.-40-in. walls	62.0	160.0	W
Water, room temperature	72.0	180.0	LB
Glass, 28°	87.0	220.0	LB
Plumbago, 20°-155°, 26.1 per cent. solid matter	96.0	240.0	O
Fine sand, 20°-155°, 51.4 per cent. solid matter	109.0	276.0	O
Coarse sand, 20°-155°, 52.9 per cent. solid matter	110.0	280.0	O
Cork, solid	131.0	333.0	LB
Plaster of Paris, 0°	105.0	266.0	LB
Plaster of Paris, 20°-155°, 36.8 per cent. solid matter	221.0	562.0	O
Slag concrete, 1 slag: 0.61 cement by weight, 50°	178.0	453.0	N
Pumice stone, 18.2 lb. per cu. ft., 50°	169.0	430.0	N
Pumice stone	187.0	477.0	LB
Brick dust, sifted	204.0	518.0	P
Asbestos, 20°-155°, 34.2 per cent. solid matter	139.0	353.0	O
Asbestos, 36 lb. per cu. ft., 600°	166.0	422.0	N
Asbestos, 36 lb. per cu. ft., 50°	221.0	562.0	N
Asbestos with air cells	416.0	1016.0	S
Cardboard, below 0°	239.0	606.0	LB

	Thermal ohms. <sup>1</sup>		
	Inch cube	Centi- meter cube	Refer- ence
Ebonite, 48°.....	251	637	LB
Petroleum, 13°.....	265	672	LB
Wood pine, parallel to fiber.....	313	796	LB
Many liquids (hydrocarbons, etc.).....	313	796	LB
Anthracite.....	317	803	LB
Chalk, 20°-155°, 25.3 per cent. solid matter...	332	844	O
Very porous slag, 22.5 lb. per cu. ft., 50°.....	356	905	N
Zinc white, 20°-155°, 8.8 per cent. solid matter	398	1010	O
Infusorial earth, 21°-175°.....	415	1050	B
Infusorial earth, 20°-155°, 11.2 per cent. solids	435	1110	O
Infusorial earth, 20°-155°, 6 per cent. solid matter.....	472	1200	O
Infusorial earth, burned, 12.5 lb. per cu. ft., 450°.....	263	1675	N
Infusorial earth, burned, 12.5 lb. per cu. ft., 50°	477	1220	N
Infusorial earth, loose, 21.8 lb. per cu. ft., 350°	427	1090	N
Infusorial earth, loose, 21.8 lb. per cu. ft., 50°	562	1430	N
Infusorial earth.....	745	1890	C
Magnesia carb., 85 per cent., 20°-188°.....	537	1370	S
Magnesia, calcined, 20°-155°, 28.5 per cent. solids.....	160	470	O
Magnesia, calcined, 20°-155°, 4.9 per cent. solids.....	544	1380	O
Magnesia, calcined, 20°-155°, 2.3 per cent. solids.....	554	1410	O
Magnesia, calcined, 21°-175°.....	572	1450	B
Charcoal, pine, 20°-155°, 11.9 per cent. solid matter.....	494	1260	O
Charcoal, from leaves, 11.9 lb. per cu. ft., 100°	537	1370	W
Charcoal, from leaves, 11.9 lb. per cu. ft., 50°	603	1530	N
Charcoal.....	723	1840	C
Feathers, 20°-155°, 2 per cent. solid matter....	577	1470	O
Sawdust, 13.4 lb. per cu. ft., 50°.....	614	1560	N
Sawdust.....	620	1570	C
Sawdust, 13.4 lb. per cu. ft., 50°.....	765	1950	LB
Cork, granulated and compressed, 20°-188°....	467	1190	S
Cork, ground, 10 lb. per cu. ft., 200°.....	614	1560	N
Cork, ground, 10 lb. per cu. ft., 50°.....	797	2030	N
Air, 20°-155°.....	143	364	O
Air, 0°.....	1700	4320	LB
Cotton wool, 20°-155°, 1 per cent. solid matter.	596	1520	O
Cotton wool, 20°-155°, 2 per cent. solid matter.	659	1570	O
Cotton wool, 5.05 lb. per cu. ft., 100°.....	572	1460	N
Cotton wool, 5.05 lb. per cu. ft., 50°.....	627	1600	N
Cotton wool.....	830	2110	C
Cotton wool, loose.....	2170	5500	LB
Cotton wool, compressed.....	2810	7120	LB
Hair felt, 20°-155°, 9.2 per cent. solid matter..	633	1610	O
Hair felt, 21°-175°.....	790	2010	B
Hair felt.....	865	2200	C
Hair felt, below 0°.....	1080	2740	LB
Lampblack, 20°-155°, 5.6 per cent. solid matter	697	1770	O
Fine quartz sand.....	718	1820	LB
Silk, 6.3 lb. per cu. ft., 100°.....	662	1690	N
Silk, 6.3 lb. per cu. ft., 50°.....	752	1920	N
Wool, sheep's, 20°-155°, 2.1 per cent. solid matter.....	616	1570	O

	Thermal ohms <sup>14</sup>		
	Inch cube	Centimeter cube	Reference
Wool, sheep's, 8.5 lb. per cu. ft., 50°.....	676	1720	N
Wool, sheep's, 8.5 lb. per cu. ft., 100°.....	745	1890	C
Wool, sheep's.....	803	2050	N
Mineral wool, 21°-175°.....	737	1870	B
Mineral wool, 0°-18°.....	1010	2570	C
Hard rubber.....	1060	2680	LB
Wood, pine, radially.....	1070	2720	LB
Loose fibrous materials, 9°.....	1540	3920	LB
Flannel.....	2650	6720	LB

B—GEORGE M. BRILL. *Trans., Am. Soc. Mech. Eng.*, XVI, p. 827. Coverings on 8-in. steam pipes.

C—J. J. COLEMAN. *Engineering*, Sept. 5, 1884, p. 237. Ice melted in cube surrounded with the materials. Temperatures 0-18° and 0-38°C. The values were given relatively to each other; to reduce them to absolute measure it is here assumed that the value for sawdust is 620, thermal ohm, inch cube units.

CE—CLEMENT and EGY.

CJ—CALVERT and JOHNSON. Relative values based on silver. Reduced here on the basis that the conductivity of silver is 1.0 in gram calories per second, centigrade, centimeter cube units.

D—DEPRETZ, Hood. "Warming and Ventilating Buildings," p. 249. Given relatively to marble, here assumed to be 10 thermal ohms, inch cube units.

H—CARL HERING. "The Proportions of Electrodes for Furnaces" (Table.) Paper read before the Am. Inst. Elec. Eng., March 31, 1910. Mean values when materials are used as furnace electrodes.

LB—LANDOLT and BOERNSTEIN tables. The values here chosen are mostly approximate means of the generally numerous and sometimes greatly differing values given by different observers. For the individual values and for the authorities see those tables. They also include values for very many other materials.

N—WILHELM NUSSEL. *Zeit. Ver. Deutsch. Ing.*, June, 1908, p. 906, table p. 1006. Materials were placed between two concentric metallic spheres or cubes. Heat generated electrically in interior. Temperature measured with thermocouples at numerous depths in the material after several days' heating. As here given they represent the resistivities at the temperatures stated, not the means over a range. Probably the best and most reliable determinations published. His conductivities are here assumed to be in terms of kilogram calories per hour, centigrade, meter cube, units; although not so stated directly in the original, it is undoubtedly what is meant. An abstract appeared in the *Eng. Digest*, August, 1908, p. 168, in which the units are reduced to thermal units, feet, inches and Fahrenheit degrees; the formula there given omits to say that it is necessary to multiply by the temperature also.

O—PROF. ORDWAY. *Trans., Am. Soc. Mech. Eng.*, Vol. VI, 1884-5, p. 168. Tested in plates 1 in. thick between two flat iron surfaces, one of them heated by steam, the heat emitted by the other being measured calorimetrically. Extended, carefully made researches; presumably very good values. There is an error in the heading in Table VII; square inch should read square meter, as in the others.

P—PECLET, Box. "Practical Treatise on Heat." Presumably ordinary weather temperatures.

S—H. G. STOTT. *Lower*, 1902. Pipe coverings. 200 ft. of 2-in. pipe heated electrically to constant temperature. Coverings were somewhat over 1 in. thick; they are here reduced to 1 in. Heat transmitted to air, hence these resistances include that at the surface.

W—WOLFF. *Jour. Frank. Inst.*, 1893. The transmission of heat from the interior to the exterior of buildings through the walls; hence ordinary weather temperatures. Prescribed by law by German Government for heat-

ing plants. Said to agree well with good American practice. The value here given is an average of all the individual ones, omitting the first one, which differed greatly from all the others

WF—WIEDEMANN and FRANZ; relative values based on silver. Reduced here on the basis that the conductivity of silver is 10 in gram calories per second, centigrade, centimeter cube, units

WQ—WOLOGDINE, QUENEAU The temperatures were about 1000°C.; the materials were those of commerce and do not refer to extra pure or to inferior grades. The present writer is of the opinion, based on the method used in the tests, that these values are probably too low.

Z—Source lost, but probably fairly good values

For further information the reader is referred to *Metallurgical and Chemical Engineering*, September, 1909, p. 383; February, 1909, p. 72; December, 1911, p. 652.

According to WILLIAM NUSSEL, thermal conductivity increases by  $\frac{1}{2}7.8$  for each degree Centigrade rise in temperature.

### THERMAL CONDUCTIVITY OF REFRACTORIES<sup>1</sup>

Woodland firebrick	Quartzite (ganister and clay)	Star silica (ganister and lime)	Magnesite (dead burned)
SiO <sub>2</sub> ..... 52 93	73 91	95 85	2 50
Al <sub>2</sub> O <sub>3</sub> ..... 42 69	22.87	0 88	0.50
Fe <sub>2</sub> O <sub>3</sub> ..... 1 98	1 48	0 79	7.00
CaO..... 0.33	0.29	1.80	2.75
MgO..... 0.38	0.31	0 14	86.50
Alkalis..... 1.55	1.20	0 39	.....
Loss on ignition.....	.....	.....	0 10
Density..... 1.91	1.91	1.56	2.46
K at 100°C.... 0.0043	0.0051	0.0056	} 0.0343 <sup>2</sup>
K at 1000°C... 0.0086	0.0086	0.0108	

<sup>1</sup> From a paper by BOYD DUDLEY, JR., read at the Atlantic City meeting of the American Electrochemical Society, April, 1915

<sup>2</sup> From 445° to 830°C. K is expressed in gram calories per second per inch cube per degree Centigrade, a peculiar unit

### Flow of Heat Inward from a Heated Plane Face<sup>1</sup>

Starting with the simple fundamental law for the flow of heat in the steady state—namely, that the amount of heat conducted varies directly as the conductivity, area, time and temperature difference, and inversely as the thickness—it is not particularly difficult to derive the solution for this case with the aid of Fourier's Series. For such derivation, however, the reader is referred to any treatise on heat conduction where he will find it given in the form:

$$T = T_0 \frac{2}{\sqrt{\pi}} \int_0^{\infty} \frac{x}{2h\sqrt{t}} e^{-\beta^2 d\beta}$$

This means that for a body initially at the zero of our temperature scale, whose plane surface is suddenly heated to and maintained at  $T_0$ , the temperature  $T$  at a distance  $x$  from this surface will be given  $t$  seconds later by this integral. As to the meaning of  $h$ , a little thought will serve to show that inasmuch as the temperature of the substance must be raised by the heat

<sup>1</sup> Taken from an article by L. R. INGERSOLL in *Eng. News*, Oct. 30, 1913.

waves as it travels into the body, the rate of this penetration will depend not only on the conductivity, but on the specific heat and density of the material as well. This is taken account of in the constant  $h$  which is defined by the relation

$$h^2 = \frac{k}{c\rho}$$

$k$ ,  $c$  and  $\rho$  being respectively the conductivity, specific heat and density of the material. The quantities  $x$ ,  $h$  and  $t$  being known,  $T$  can be determined. Tables I and II give the values of this integral, and of the constant  $h^2$ , or *thermal diffusivity*.

TABLE I.—VALUES OF INTEGRAL  $E = \frac{2}{\sqrt{\pi}} \int_0^\infty \frac{x}{2h\sqrt{t}} e^{-\beta^2 d\beta}$

$x/2h\sqrt{t}$	$E$	$x/2h\sqrt{t}$	$E$	$x/2h\sqrt{t}$	$E$
0.00	1.000	0.45	0.525	1.40	0.048
0.02	0.987	0.50	0.480	1.50	0.034
0.04	0.955	0.55	0.437	1.60	0.024
0.06	0.932	0.60	0.396	1.70	0.016
0.08	0.910	0.65	0.358	1.80	0.0109
0.10	0.888	0.70	0.322	1.90	0.0072
0.12	0.865	0.75	0.288	2.00	0.0047
0.14	0.843	0.80	0.258	2.10	0.0030
0.16	0.821	0.85	0.229	2.20	0.0019
0.18	0.800	0.90	0.203	2.30	0.0011
0.20	0.777	0.95	0.179	2.40	0.0007
0.25	0.724	1.00	0.157	2.50	0.0004
0.30	0.671	1.10	0.120	2.60	0.0002
0.35	0.621	1.20	0.090	2.70	0.0001
0.40	0.572	1.30	0.066	$\infty$	0.0000

*Examples.*—The use of these tables is best shown by solving some specific examples:

1. A massive granite block at 20°C. (68°F.) has one face (rapidly) heated to 200°C. (392°F.). What will be the temperature at a depth of 10 cm. (4 in.) after 1 hour?

Since the theory is based on the assumption of an initial temperature of zero the temperature scale must be shifted in this case by subtracting 20°, which will be added again later. Taking  $h^2$  from Table II as 0.0155,  $t$  as 3600 (seconds) and  $x$  as 10 (cm.), the quantity  $x/2h\sqrt{t}$  becomes 0.67. This gives, from Table I,  $E = 0.34$ ; hence the rise in temperature would be  $T = 180E$ , or 61°, making a final temperature of 81°C. (178°F.).

2. The surface of a dry soil initially throughout at 6°C. (43°F.) is cooled to -20°C. (-4°F.). How long before water-pipes at depth of 152 cm. (5 ft.) will be in danger of freezing?

Here we have, after shifting the temperature scale,

$$-6 = -26E, \text{ or } E = 0.23$$

From Table I, then,  $x/2h\sqrt{t} = 0.85$ , which, with  $h^2 = 0.0031$ , gives  $t = 2,600,000$  seconds or 30 days.

TABLE II.—VALUES OF THERMAL CONDUCTIVITY CONSTANTS IN C. G. S.<sup>1</sup> UNITS<sup>2</sup>

Material	Temperature, deg. C.	Conductivity, $k$	Diffusivity, $h^2$
Air.....	0	0.000055	0.179
Aluminum....	18	0.480	0.826
Brass (yellow).....	0	0.204	0.339
Brick (firebrick)....	0-800	0.0040	0.0074
Brick (in masonry)....		0.0020	0.0050
Concrete (cinder)....		0.00081	0.0031
Concrete (stone)....		0.0022	0.0058
Copper.....	18	0.918	1.133
Cork (ground)....		0.00012	0.0017
Glass (ordinary).....		0.0024	0.0057
Granite.....		0.0081	0.0155
Ice.....		0.0052	0.0112
Iron (wrought or mild steel)....		0.1436	0.173
Iron (cast, also high-carbon steel)....		0.108	0.121
Lead.....	18	0.0827	0.237
Limestone.....		0.0050	0.0092
Magnesium carbonate (85 per cent. steam-pipe covering)....		0.00017	
Marble (white).....		0.0050	0.0090
Nickel.....	18	0.142	0.152
Rock material, average....		0.0042	0.0118
Sandstone.....		0.0050	0.0133
Silver.....	18	1.008	1.737
Snow (fresh)....		0.0003	0.0033
Soil (average, damp)....		0.0037	0.0055
Soil (very dry)....		0.00088	0.0031
Water.....		0.00143	0.00143
Wood (dry pine—across grain).....		0.00009	0.00068
Wood (dry pine—with grain).....		0.00030	0.0023

<sup>1</sup> The use of this system is almost compulsory in cases where thermal diffusivity is involved, since it is the only one in common use which is consistent in its choice of fundamental units. Thus the steam engineer's conductivity unit of the B t u. per hour, per square foot, per degree F., per inch in thickness, is not available in this case since it involves two different units of length, i.e., the inch and foot. Similar objections may be raised against most of the other units in common use with the exception of the C. G. S.

Most of the values for metals are those of JÄGER and DIESSELHORST, *Abh. d. phys.-tech. Reichsanstalt*, Vol. 3, p. 269 (1900). The others have been compiled from various sources. When not otherwise specified, ordinary temperatures are assumed.

<sup>2</sup> This table is also taken from INGERSOLL'S article. Some of these constants differ from those given in the table on p. 163, but the differences are not serious, and since his diffusivity constants have been computed on this basis, it seems better to let the table stand as originally printed.

### Flow of Heat Inward from Two Heated Faces

If a plate or slab of thickness  $l$  and initial temperature zero have both its faces suddenly heated to and kept at  $T_0$ , the temperature  $T$  in the middle plane, which will obviously be the last part of the body to heat up, may be obtained from the equation

$$T = T_0 \left( 1 - \frac{4}{\pi} 10^{-0.434} \frac{h^2 \pi^2 t}{l^2} + \frac{4}{3\pi} 10^{-0.434} \frac{9h^2 \pi^2 t}{l^2} - \dots \right)$$

$t$  being the time in seconds and  $h^2$  the thermal diffusivity. To simplify computation, the values of this series have been tabulated as in Table III.

TABLE III.—VALUES OF THE FUNCTION

$$y = 1 - \frac{4}{\pi} \left( 10^{-x} - \frac{1}{3} 10^{-9x} + \frac{1}{5} 10^{-25x} - \dots \right) \text{ where } x = 0.434 \frac{h^2 \pi^2 t}{l^2}$$

$x$	$y$	$x$	$y$	$x$	$y$
0.01	0.0000	0.11	0.0546	0.36	0.4444
0.02	0.0000	0.12	0.0692	0.38	0.4693
0.03	0.0000	0.13	0.0848	0.40	0.4931
0.035	0.0001	0.14	0.1009	0.45	0.5482
0.04	0.0005	0.15	0.1176	0.50	0.5974
0.045	0.0010	0.16	0.1345	0.60	0.6802
0.05	0.0021	0.17	0.1517	0.70	0.7460
0.055	0.0037	0.18	0.1690	0.80	0.7982
0.06	0.0055	0.19	0.1862	0.90	0.8397
0.065	0.0081	0.20	0.2033	1.00	0.8727
0.07	0.0113	0.22	0.2372	1.25	0.9284
0.075	0.0150	0.24	0.2702	1.50	0.9597
0.08	0.0194	0.26	0.3022	1.75	0.9774
0.085	0.0241	0.28	0.3331	2.00	0.9873
0.09	0.0294	0.30	0.3727	2.50	0.9960
0.095	0.0351	0.32	0.3912	3.00	0.9987
0.10	0.0412	0.34	0.4184	3.50	0.9996
				4.00	0.9999

*Examples.*—A dry spruce cross-tie  $11.4 \times 17.8$  cm. ( $4\frac{1}{2} \times 7$  in.) in section and 71 cm. (28 in.) long, and at an initial temperature of  $15^\circ\text{C}$ . ( $59^\circ\text{F}$ .), is placed in an oven which heats its surface to  $137^\circ\text{C}$ . ( $278^\circ\text{F}$ .) for  $10\frac{1}{2}$  hours. What should be the temperature at the end of this period for a point near the center of the tie?

As the heat penetration will be largely due to conduction across the smallest dimension of the tie we shall neglect the other faces altogether. We have then, effectively, a plate of thickness 11.4 cm. and diffusivity 0.0068 (pine wood in Table II), which give  $x = 0.85$ . Then from Table III,  $y = 0.82$ , making a rise in temperature of  $0.82 (137^\circ - 15^\circ)$ , or  $100^\circ$ . This gives a final temperature of  $115^\circ\text{C}$ . ( $239^\circ\text{F}$ .). In an actual experiment this was found to be  $113^\circ\text{C}$ ., checking our theory much more closely than could be expected, considering the approximations we have made in neglecting the other faces.

In the same way we can readily show by a few minutes' work with a slide-rule that the center of a plate of steel 2.54 cm. (1 in.) thick, which is plunged into molten lead, should rise to within 2 per cent. of the temperature of its faces in less than half a minute; the center of a firebrick 6.3 cm. ( $2\frac{1}{2}$  in.) thick, heated by flue gases in a regenerator, should show more than half its surface change in temperature in 10 minutes, and more than three-quarters in 20 minutes; a disk of glass 20.3 cm. (8 in.) thick, which has been subjected to a recent heating or cooling of a dozen degrees should be kept with faces at constant temperature for upwards of 10 hours to insure that the interior temperature is uniform to a small fraction of a degree.



## Relative Conductivities of Metals for Heat and Electricity

The following table, compiled from various sources, is intended to show merely the general correspondence between conductivity for heat and for electricity. For ordinary work, the table of heat conductivities just preceding, and of electric resistivity just following, should be used. The electric conductivities are the reciprocals of the resistivities given in the later tables.

Metal (in vacuo)	Heat	Electricity	Metal (in vacuo)	Heat	Electricity
Silver	100	100	Iron.....	11.9	14.44
Copper.	74	77.43	Steel.....	10.3	
Gold. . .	54.8	55.19	Platinum. . .	9.4	10.53
Aluminum .	31.33		Lead. ....	7.9	7.77
Zinc . . . .	28.1	27.39	German silver..	6.3	6.0
Brass . . . .	24	22.0	Antimony.....	4.03	
Cadmium. . .	20.06		Bismuth. . . .	1.8	1.8
Tin. ....	15.4	11.45	Mercury.. . .	1.3	

## RELATION OF HEAT AND ELECTRIC CONDUCTIVITIES

Materials	Thermal cond. in gram. cal per sec. per cm. <sup>2</sup> at 18°C./Electrical cond. in recip. ohms per cm. <sup>2</sup> at 18°C.
Aluminum.....	$1.48 \times 10^{-6}$
Bismuth.....	$2.08 \times 10^{-6}$
Cadmium.....	$1.66 \times 10^{-6}$
Copper, casting . . . .	$1.80 \times 10^{-6}$
Copper, electrolytic. . .	$1.81 \times 10^{-6}$
Gold.....	$1.69 \times 10^{-6}$
Lead.....	$1.73 \times 10^{-6}$
Iron (1% C.)....	$1.73 \times 10^{-6}$
Nickel.....	$1.65 \times 10^{-6}$
Platinum.....	$2.09 \times 10^{-6}$
Palladium.....	$1.82 \times 10^{-6}$
Silver.....	$1.81 \times 10^{-6}$
Zinc, coml. . . .	$1.85 \times 10^{-6}$
Constantan.. . .	$2.39 \times 10^{-6}$
Manganin.....	$1.98 \times 10^{-6}$
Climax resistance . .	$3.12 \times 10^{-6}$
Climax 193 resistance	$3.00 \times 10^{-6}$
Nichrome IV.....	$3.81 \times 10^{-6}$
Nichrome. . . . .	$3.56 \times 10^{-6}$
Advance resistance . .	$2.69 \times 10^{-6}$
Monel metal.....	$2.54 \times 10^{-6}$

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RESISTIVITY OF METALS  
(Microhms per cm.<sup>2</sup>)

	-160°	0°	18°	100°	Temp. coeff. at 0°
Aluminum.....	0.81	2.8	2.94	4.13	0.0040
Antimony.....		30.0	40.5		0.0041
Beryllium.....			18.5		
Bismuth.....		55.55	119.0	160.3	0.0035
Cadmium (drawn)...	2.72	7.0	7.54	9.82	0.0042 <sup>2</sup>
Copper (drawn)...	0.49 <sup>1</sup>	1.58	1.78	2.36	0.0039
Calcium.....		7.5	10.5		0.0040
Cobalt.....			6.24 <sup>3</sup>		0.0033 <sup>3</sup>
Gold.....	0.68		2.42	3.11	0.0037
Arsenic.....		33.3			
Iridium.....			5.3		
Iron.....			9-15	16.8	0.0062
Iron (wrought)...	5.4		13.9	18.8	0.0058
Lead (drawn)...	7.43	19.0	20.8	27.7	0.0039
Lithium.....		8.4	4.46		
Magnesium.....		4.35			0.0038
Mercury.....		94.07	95.57		0.00072
Molybdenum (hard)			4.8 <sup>2</sup>		0.0050 <sup>2</sup>
Steel.....			19.9	25.6	
Nickel.....	5.9		6.9	15.7	0.0066 <sup>4</sup>
Osmium.....			9.5 <sup>3</sup>		
Palladium.....	2.78	10.21	10.7	13.8	0.0035 <sup>3</sup>
Platinum.....	2.1 <sup>4</sup>	9.0	11.0	14.0	0.0039 <sup>3</sup>
Potassium.....		6.64			
Rhodium.....	0.70		6.0	6.60	
Rubidium.....	2.5	11.6			
Silver.....	0.56	1.50	1.65	2.13	0.00377
Sodium.....	1.0	4.74			
Strontium.....			25.0 <sup>3</sup>		
Tantalum.....			14.6		0.0033 <sup>3</sup>
Tellurium.....			21.0 <sup>1</sup>		0.0040
Thallium.....	4.08	17.6			
Thorium.....			18.0		
Tin (drawn).....	3.5	10.0	11.3	15.3	0.0043
Tungsten (annealed)		4.4 <sup>2</sup>	5.4	6.65	0.0051 <sup>2</sup>
Zinc.....	2.2	5.6	6.1	7.9	0.00365

<sup>1</sup> At -183°. <sup>2</sup> At 25°. <sup>3</sup> At 20°. <sup>4</sup> At -204°. <sup>5</sup> From 18° to 100°.  
<sup>6</sup> Annealed. Hydrogen reduced, 8.96

## ALLOYS<sup>1</sup>

	-160°	0°	18°	100°	Temp. coeff. at 0°
German silver <sup>2</sup> ...		26.6		27.6	0.0003
Nichrome (60 Ni; 22 Cr).....	4.1	109.5	6.6		0.00017
Brass (Zn, 34.3%)...					0.0010
Constantan.....			49.0	49.1	-0.000050 to +0.000050
Manganin <sup>3</sup> .....	43.13		43.50	42.1	0.000002 to 0.000039 <sup>4</sup>
Phosphor bronze.....			5-10		
Woods alloy.....			31.25		
Monel metal.....			40		0.0019

<sup>1</sup> See table on p. 198 for other resistance alloys.  
<sup>2</sup> 62 per cent. Cu, 15 Ni, 22 Zn.  
<sup>3</sup> 84 per cent. Cu, 4 Ni, 12 Mn.  
<sup>4</sup> Most samples of manganin have a zero temperature coefficient from 30° to 40°C.

ELECTRIC RESISTIVITY OF REFRACTORIES

	Cold	800°C.	900°C.	1000°C.	1100°C.	1200°C.	1300°C.	1400°C.	1500°C.
	<125 meg.	2 38 meg	765,000	300,000	126,000	62,000	30,900	16,500	8,420
	<127 meg.	835,000	477,000	197,000	75,000	29,500	15,200	10,100	8,590
	<137 meg.	5 00 meg	1,24 meg.	708,000	560,000	193,000	67,400	22,400	2,500
	<134 meg.	558,000	224,000	131,300	53,800	7,710	2,100	968	412
	<133 meg.	109,000	32,500	17,200	9,200	6,100	5,600	2,200	1,100
	<132 meg.	57,600	20,600	10,800	6,390	4,160	2,460	1,420	890
		12,550	8,220	7,420	6,320	4,160	2,420	1,435	745
		803 ohms	375	171	78	63	77	85	41
		45	5.25	4.11	3.11	2.45	2.05	1.74	1.62

From a paper by M. L. HARTMANN, A. P. SULLIVAN

resistivity of copper is increased by the addition of any impurity. The resistivity is as follows: Aluminum, 1.9; Calcium, 0.17; Magnesium, 2.0; Silicon, 1.62.

3,148  
1,642  
1,318  
1,379

Iron  
Tin  
Solder (2 Pb : 1 Sn)..  
Lead.....

Handbook."

# 198 METALLURGISTS AND CHEMISTS' HANDBOOK

## PROPERTIES OF RESISTOR WIRES

Material	Composition	Resistivity, 20°C.		Maximum Working temp., °C.
		Microhm-cm.	Ohm-ft.	
Copper.	Annealed	1 724	10 37	260
German silver	Cu 58, Ni 18, Zn 24	33 3	200 0	260
Manganin	Cu 84, Ni 4, Mn 12	41 4	249 0	100
		73 8	443 0	
Monel metal	Cu, Ni	42 6	256 0	480
Therilo	Cu 85, Mn 13, Al 2	46 7	280 0	200
German silver	Cu 50, Ni 30, Zn 20	48 2	290 0	
Advance	Cu, Ni	48 8	294 0	370
La la	Cu, Ni	49 0	295 0	
Raymur	Cu, Ni	49 0	295 0	
Constantan	Cu 60, Ni 40	50 0	300 0	
Tico	Nickel steel	85 9	517 0	
Phenix	Nickel steel	87 0	524 0	540
Chimax	Fe 72, Ni 28	87 2	525 0	540
Alido	Ni - Cr	95 5	575 0	1090
Phet	Ni - Cr	96 0	580 0	
Arone	Ni - Cr	99 6	600 0	900
Nichrome II	Ni 64, Fe 25, Cr 11	109 5	660.0	1100
Osism	Mn 3			
Palantico	Ni - Cr	119 5	720.0	870
Platin				
Potass-hite				
Rhodium (a)				
Rubidium (n)				
Silver				
Sodium				
Strontium				
Tantalum				
Tellurium				
Thallium				
Thorium				
Tin (drawn)				
Tungsten (annealed)				
Zinc				

### Wien's Rule for Power Transmission

The minimum cross-sectional area of conductor is that for which the annual capital outlay is equal to the annual cost of interest and depreciation.

This rule summarizes partially the comparison of electric conductors.

	<sup>1</sup> At -183°	<sup>2</sup> At 25°	<sup>3</sup> At 25°	Commercial copper	Aluminum steel, 7 strands	Aluminum-steel, 37 strands
<sup>4</sup> Annealed.	Hydrogen reduced, 8.9					
				ALLOY		
	-160°	0°	1.25		3.55	3 85
					51 5	49 0
German silver <sup>2</sup>		26.6				
Nichrome (60 Ni; 22 Cr)	4.1	109 5	6.6		18 2 × 10 <sup>-6</sup>	17.25 × 10 <sup>-6</sup>
Brass (Zn, 34.3%)					29	32
Constantan			40 0		16	17 to 18
Manganin <sup>3</sup>	43.13		43.50		1.943	2.05
Phosphor bronze			5-10			
Woods alloy			31.25			
Monel metal			46		1 395	1 43
					0.73 <sup>4</sup>	0.835

<sup>1</sup> See table on p. 198 for other resistance alloys.

<sup>2</sup> 62 per cent. Cu, 15 Ni, 22 Zn.

<sup>3</sup> 84 per cent. Cu, 4 Ni, 12 Mn.

<sup>4</sup> Most samples of manganin have a zero temperature to 40°C.

## FUSING CURRENTS FOR COPPER WIRE

The following table has been tested for copper-wire fusing currents and was found to be closely correct for average conditions, according to the *Electrical Review*.

Size wire, B. & S.	Fusing current, ampere	Size wire, B. & S.	Fusing current, ampere
30	10	18	80
28	15	17	100
26	20	16	120
25	25	15	140
24	30	14	160
22	40	13	200
21	50	12	240
20	60	11	280
19	70	10	330

If heat be developed in an electrical conductor faster than it can be dissipated from its surface by radiation and convection, the temperature will rise. The allowable rise in temperature is one of the limiting features of the current-carrying capacity of any conductor, since the rate at which heat will be dissipated will depend upon many conditions, such as the size and structure of the conductor, the kind and amount of insulation, if any, and the location with respect to other bodies.

The general subject of fusing currents for copper wire was investigated by W. H. Preece, who developed the formula:  $I = a d^2$  where  $I$  is the fusing current in amperes,  $d$  is the diameter of the wire in inches, and  $a$  is a constant depending on the material. He found the following values for  $a$ .<sup>1</sup>

Copper . . . . .	10,244	Iron . . . . .	3,148
Aluminum . . . . .	7,585	• Tin . . . . .	1,642
Platinum . . . . .	5,172	Solder (2 Pb : 1 Sn). . . . .	1,318
German silver . . . . .	5,230	Lead . . . . .	1,379
Platinoid . . . . .	4,750		

<sup>1</sup> "Standard Electrical Handbook."

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WIRE RESISTANCE TABLE<sup>1</sup>

Gage No. B. & S.	Diam. in mils. 20°C.	Cross-section at 20°C., sq. in.	Copper <sup>1,2</sup> ohms per 1000 ft.	Aluminum, <sup>3</sup> ohms per 1000 ft.
0000	460.0	0.1662	0.04901	0.0804
00	384.8	0.1045	0.07793	0.128
1	289.3	0.06573	0.1239	0.203
2	257.6	0.05213	0.1563	0.256
4	204.3	0.03278	0.2485	0.408
6	162.0	0.02062	0.3951	0.648
8	128.5	0.01297	0.6282	1.03
10	101.9	0.008155	0.9989	1.64
12	80.81	0.005129	1.588	2.61
14	64.08	0.003225	2.525	4.14
16	50.82	0.002028	4.016	6.59
18	40.30	0.001276	6.385	10.5
20	31.96	0.0008023	10.15	16.7
22	25.35	0.0005046	16.14	26.5
24	20.10	0.0003173	25.67	42.1
26	15.94	0.0001996	40.81	67.0
28	12.64	0.0001255	64.90	106.0
30	10.03	0.00007894	103.2	169.0
32	7.95	0.00004964	164.1	269.0
34	6.305	0.00003122	260.9	428.0
36	5.000	0.00001964	414.8	689.0
38	3.965	0.00001235	659.6	1080.0
40	3.145	0.000007766	1049.0	1720.0

<sup>1</sup> "Standard Electrical Handbook."<sup>2</sup> Standard annealed, at 20°C.<sup>3</sup> Hard drawn, at 20°C.

**Sparking Distances in Electrical Installations.**—A mass of reliable data is now available concerning sparking distance between electrodes of simple geometrical form (needle points, disks, spheres, etc.), under various conditions, but little information has hitherto been available concerning sparking distances between metallic conductors and walls in workshops and on switchboards, etc. This problem, which is obviously of great practical importance was recently investigated by GINO REBORA (see also *Atti dell' Associazione Elettrot. Italiana* No. 31,913), and the first result deduced was the fact that a grain of dust or a fine hair or fiber would often suffice to start discharge from a high-tension conductor. A point or angularity in a conductor may cause a discharge to occur which would otherwise require 30 per cent. higher pressure than that actually operative; it is therefore very desirable that all metals subject to high-tension current should be as free as possible from points and angularities of any kind. The black lines frequently seen on switchboards, and walls behind high-tension conductors reveal the presence of sustained feeble discharges which bombard the surface near the conductor with particles of dust.

From observations made in 30 installations, working at pressures between 3000 and 110,000 volts, REBORA derives a curve

showing the minimum safe distance between conductor and earthed walls or metal covers, etc. As shown by the following data, his limits are rather less stringent than those recommended (but not always observed) by the G. E. C.:

P. D.		20	40	60	80	100	Kilovolts
Minimum distance between conductor and earth.....	{ Rebera	100	200	330	450	590	Mm.
	{ G. E. C.	150	300	450	620	770	Mm.

As regards the effective height of porcelain insulators of pylon form, used as intermediate insulators on distribution boards, etc., this height increases almost linearly at the rate of 5 or  $5\frac{1}{2}$  mm. per kilovolts for pressures up to 80 kv., and then increases more rapidly, to a total of 580 mm. for 100 kv. and 930 mm. for 130 kv. In deriving these data, MAGRINI, A. E. G., and RICHARD GINGORI insulators were tested.

In the course of investigations conducted in the Ecole Polytechnique de Milan with a view to determining the laws of discharge between conductor and masonry, etc., copper wires, 2, 4, 5, 6 and 8 mm. in diameter, a bar  $3 \times 10$  mm., and a brass tube  $2\frac{3}{2}$  mm. in external and internal diameter were used. As second electrodes were employed in turn walls of cement, stone, hollow brick, eternite, and metal frameworks. The maximum testing pressure available was 100 kv. at 42 cycles per second. When the conductor under test was pointed straight at the wall, breakdown occurred at 20 per cent.—25 per cent. lower P. D. (for separations of 100 to 250 mm.) than would be required to produce discharge between needle points the same distance apart. This is a result of great practical importance, since live metal parts are frequently so arranged in high tension installations as to produce reductions in the factor of safety.

#### RELATIVE CATHODE LOSSES IN GLOW DISCHARGE

(Platinum taken as 1)

	A	B
Palladium.....	1 05	1 10
Gold.....	0 98	0 88
Silver.....	3.46	3 08
Molybdenum.....	0.44	0.41
Tungsten.....	0.62	0.58
Iron.....	0.81	1 05
Nickel.....	0.81	1.13

A = volume loss relative to Pt.

B = loss of atoms relative to Pt.

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### Electric Arcs<sup>1</sup>

MRS. AYRTON'S formula for carbon arcs,  $E = \alpha + \beta l + \frac{\gamma + \delta l}{i}$ , has been shown to hold for short stable arcs between metals.  $E$  is the voltage across the arc,  $i$  the current in amperes, and  $l$  the length in millimeters of the arc in air at 76 cm. pressure. The formula does not hold for long arcs or cored carbons. For stability, an arc requires an external resistance  $R$  which must be less than  $\frac{[E_x - (\alpha + \beta l)]^2}{4(\gamma + \delta l)}$  ohms, where  $E_x$  is the total available voltage; or  $E_x$  must exceed  $\alpha + \beta l + 2\sqrt{R(\gamma + \delta l)}$ . If  $R$  is too small the arc hisses, in which case the current is independent of the voltage across the terminals. The constants for carbon refer only to the particular sizes and quality used by MRS. AYRTON.

Metal	$\alpha$	$\beta$	$\gamma$	$\delta$
C.....	38 88	2 074	11 67	10 54
Fe ..	15 73	2 52	9.44	15 02
Ni ..	17 14	3.89	0.0	17 48
Co . . .	20 71	2 05	2.07	10 12
Cu ..	21 38	3 03	10.69	15 24
Pd .. .	21 64	3 70	0.0	21 78
Ag .....	14 19	3.64	11.36	19.01
Pt .....	24 29	4 80	0 0	20.23
Au .....	20 82	4 62	12.17	20.97

### Thermoelectricity<sup>2</sup>

When two different metals are brought into contact so that the two junctions are at different temperatures, there will usually be a slight current of electricity produced. The effective electromotive force is

$$\text{volts} = \frac{(T_2 - T_1)[(B' - B'') + (C' - C'')\left(\frac{T_2 + T_1}{2}\right)]}{100,000,000}$$

where  $T_2$  and  $T_1$  are the temperatures of the junctions, and  $B$  and  $C$  constants as given in the following table:

Metal	$B$	$C$	Metal	$B$	$C$
Iron .....	+1734	-4.87	Silver .. .	+214	+1.50
Steel.....	+1139	-3.28	Gold.....	+283	+1.02
Soft platinum.....	+ 61	-1.10	Copper.....	+136	+0.95
Hard platinum.....	+ 260	-0.75	Lead.....	0	+0.00
Magnesium.....	+ 244	-0.95	Tin.....	- 43	+0.55
German silver ..	+1207	-5.12	Aluminum ..	- 77	+0.39
Zinc . . .	+ 234	+2.40	.....	.....	.....

<sup>1</sup> KAYE and LABY'S "Chemical and Physical Constants."

<sup>2</sup> "Encyclopedia Americana," Vol. XV, "Thermoelectricity."



The behavior of nickel is anomalous. Antimony and bismuth produce the greatest current of any two metals, but here again, the constants vary greatly according to the absolute temperatures of the junctions.

PENETRATING POWER OF X-RAYS<sup>1</sup>

Substance	Specific gravity	Transparency	Substance	Specific gravity	Transparency
Water.....	1.00	1.000	Copper.....	8.92	0.084
Aluminum...	2.67	0.380	Silver.....	10.24	0.070
Glass .....	2.70	0.340	Lead .....	11.30	0.055
Tin .....	7.29	0.118	Mercury ...	13.59	0.044
Zinc .....	7.16	0.116	Gold .....	19.63	0.030
Iron...	7.78	0.101	Platinum.	21.53	0.020
Nickel.	8.51	0.095			

<sup>1</sup> The wave length of X-rays is apparently about  $10^{-2}$  to  $10^{-8}$  cm. The table is from the *General Electric Review*.

### Specific Gravity Tables

The following tables give the average specific gravities of most solids and liquids of importance in mining and metallurgy. There are separate tables for water, mercury, gases and the most important minerals.

Comparison of Standards.—Hydrogen, air and water are the three standards commonly used in the determination of the specific gravity of gases, liquids and solids. The relative densities of these standards are as follows:

Air (dry) is 14.418 times as heavy as hydrogen, at the same temperature and pressure, volume for volume.

Water (max. density, 4°C.) is 773 times as heavy as dry air at 30°F., bar. 29.92 in.; and 815 times as heavy as dry air at 60°F., bar. 30 in., volume for volume.

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## SPECIFIC GRAVITIES AND UNIT WEIGHTS OF SOLIDS AND LIQUIDS.

Substance	Average sp. gr. (water = 1)	Average weight (lb. per cu. ft.)
Aluminum (99.75% Al)...	2.703	168.7
(molten) .....	2.38	138.6
Amber .....	1.06-1.11	67.6
Antimony .....	6.71	419.0
Argon, (liquid, -185°) ..	1.4	87.3
Arsenic (amorphous) ..	5.71	358.0
(crystallized) .....	5.73	358.0
(molten) .....	5.71	358.0
Asbestos .....	3.2	200.0
Ashes (packed) .....	0.72	45.0
Asphalt (1 to 1.8) ..	1.4	87.0
Barium .....	3.78	236.0
Beeswax .....	0.96	59.9
Beryllium .....	1.93	120.0
Bismuth (com'l) .....	9.74-9.92	614.0
(distilled) .....	9.78	611.0
(molten 1355°C) ..	10.04	627.0
Bone .....	1.7-2.0	115.3
Boron .....	2.45	153.0
Brass, cast (7.8 to 8.4) 70 Cu, 30 Zn .....	8.1	508.0
rolled, 70 Cu, 30 Zn ..	8.4	524.0
Brick (fire) .....	.....	140-150
(soft) .....	.....	100.0
Brickwork, masonry (1.8 to 2.3) .....	.....	110-140
Bromine (at 0°C) .....	3.187	199.0
Bronze (8.7 to 8.9) ..	8.8	550.0
Cadmium .....	8.60-8.70	540.0
(molten) .....	7.99	499.0
Cæsium .....	1.87	117.0
Calcium .....	1.85	115.0
Celluloid .....	1.4	87.4
Cement, set .....	2.7-3.0	168-187
Cerium .....	6.68	417.0
Chalk .....	2.5	156.0
Charcoal .....	.....	13.0
Chromium .....	6.52-6.73	414.0
Clay (1.8 to 2.6) .....	2.2	137.3
Coal, anthracite (1.3 to 1.7) ..	1.5	93.6
bituminous (1.2 to 1.5) ..	1.3	81.15
cannel, gas coal (1.18 to 1.28) ..	1.23	76.78
lignite, brown coal ..	1.1	68.67
Cobalt .....	8.50-8.92	540.0
Coke, loose piled .....	.....	20-30
Concrete .....	2.3	144.0
Copper, cast (8.6 to 8.8) ..	8.7	543.0
deposited .....	8.92	557.0
molten .....	8.22	513.0
rolled (8.8 to 8.95) ..	8.9	556.0
Cork .....	0.24	14.98
Diamond .....	3.52	.....
Diatomite .....	0.24	.....
Earth, loose to well rammed ..	.....	76-95
wet, flowing mud .....	.....	105-115
Ebonite .....	1.15	71.7
Emery .....	4.0	250.0
Erbium .....	4.97	310.0
Gallium .....	5.89	370.0
molten .....	6.08	.....
Germanium .....	5.47	335.0
German silver .....	8.45	527.5

For minerals, see special table, p. 210. For woods, see p. 207. For organic compounds, see p. 814. For gases, see p. 214.

**SPECIFIC GRAVITIES AND UNIT WEIGHTS OF SOLIDS AND LIQUIDS.**  
*Continued*

Substance	Average sp. gr. (water = 1)	Average weight (lb. per cu. ft.)
Glass.....	2.52	157.0
(heavy flint).....	2.92	200.0
Gold (19.25 to 19.37) (20 Karat = 16.47)...	19.31	
coin, U. S.....	16.95	
Graphite (average value).....	2.2	137.0
Gravel, loose.....		95-120
Greenstone (trap).....		170-200
Gypsum, ground or calcined, loose.....		56.0
well shaken.....		64.0
uncalcined.....		130-150
Ice.....	0.92	57.5
Iodine.....	4.95	309.0
Indium.....	7.12	444.0
Iridium.....	22.42	1400.0
Iron, cast gray, 7.08, white	7.6	450.0
(molten 1355°C).....	6.88	429.0
rolled.....	7.68	480.0
wrought, sheet (7.6 to 7.9)	7.8	485.0
Ivory.....	1.82-1.92	
Kieselguhr.....	0.24	
kiln dried.....	0.34	
Lanthanum.....	6.15	384.0
Lead.....	11.35	700.0
(molten 1535°C).....	10.61	664.0
Lignite.....		75.0
Lime (quicklime).....	1.5	93.75
ground, loose (66 lb. per bushel)		53.0
Limestone.....	2.7	168.0
Lithium.....	0.59	36.8
Loam.....		65-100
Magnesium.....	1.74	109.0
molten.....	1.572	
Manganese.....	7.39 <sup>2</sup>	461.0
Manganin.....	8.42	
Marble (2.5 to 2.8).....	2.65	160-180
Marl.....		100-140
Mercury (32°F.) (see table on p. 176 also)	13.5955	850.0
(62°F.).....	13.555	847.0
solid, -40°F.....	15.632	976.0
Mica.....	2.8	175.0
Molybdenum.....	10.2	636.0
Monel metal.....	8.80	
Mortar.....		90-105
Neodymium.....	6.956	434.0
Nickel.....	8.86	553.0
Niobium.....	12.7	793.0
Oils (0.910 to 0.975), weight given in pounds		
per gallon:		
Animal, lard.....	0.916	7.44
sperm (pure).....	0.880	7.34
whale.....	0.925	7.72
Mineral, petroleum (crude).....	0.77-1.06	
gasolene.....	0.700	5.84
kerosene (coal oil).....	0.800	6.68
naphtha.....	0.730 <sup>1</sup>	6.09
Vegetable, cottonseed.....	0.923	7.70
linseed (boiled).....	0.933	7.79
(raw).....	0.780	6.51
olive.....	0.917	7.65
rape (colza).....	0.915	7.63

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## SPECIFIC GRAVITIES AND UNIT WEIGHTS OF SOLIDS AND LIQUIDS. *Continued*

Substance	Average sp. gr. (water = 1)	Average weight (lb per cu ft.)
Osmium...	22.48	1403.0
Palladium..	12.16	743.0
Peat (dry, unpressed)	...	20-30
Phosphorus (red)	2.34	146.0
(white) ..	1.837	115.0
Pitch .....	1.155	72.0
Platinum wire..	21.5	1342.0
Plaster of Paris..	1.50-1.80	103.2
Porcelain .....	2.3-2.5	149.6
Potassium .....	0.875	54.9
Præcodymium.	6.475	404.0
Pumice.....		50-60
Quartz (fused, clear).	2.21	
(fused, translucent)	2.10	
Rhodium .....	12.60	787.0
Rosin .....	1.1	68.67
Rubber, hard (pure).	1.12-1.25	
Rubber, hard (commercial)	1.25-1.40	
Salt .....		45.0
Samarium .....	7.75	484.0
Sand (dry)		100.0
(wet) .....		130.0
Sandstone (2.1 to 2.7)	2.4	150.0
Selenium (gray metal)	4.8	293.0
(red) .....	4.47	279.0
Shale (2.4 to 2.8)	2.6	162.0
Silicon (amorphous).	2.00	125.0
(crystallized).	2.195	137.0
Silver (cast)...	10.75	671.0
(electrolytically deposited)	10.53	655.0
(molten) .....	9.51	594.0
Slate (2.7 to 2.9) ...	2.7	169.0
Snow (fresh, dry)		5-12
(wet) .....		15-50
Soapstone.		166.0
Soda ash .....	1.2	74.0
Sodium .....	0.972	60.7
Steel (7.69 to 7.93) <sup>1</sup>	7.85	490.0
Strontium.....	2.54	159.0
Sugar .....	1.6	
Sulphur .....	1.96-2.07	125.0
Tallow .....	0.94	58.7
Tantalum .....	16.6	1036.0
Tar .....	1.0	62.5
Tellurium.	6.25	390.0
Thallium .....	11.85	740.0
Thorium .....	12.16	759.0
Tin (cast) .....	7.29	459.0
(molten) .....	7.02	438.0
Titanium .....	4.87 <sup>2</sup>	304.0
Traprock.	3.0	187.0
Tungsten .....	19.3-20.2	1248.0
Uranium .....	18.69	1667.0
Vanadium .....	5.50	337.0
Water <sup>2</sup> (max density 4°C).	1.0	62.428
(pure, 62°F)	0.999	62.366
(pure, 212°F)	0.958	59.806
sea, average	1.028	64.176

<sup>1</sup> Pure and soft. The specific gravity decreases as the carbon increases.

<sup>2</sup> See special table on p. 208 for water.

<sup>3</sup> For minerals, see special table, p. 210. For woods, see p. 207. For organic substances, see p. 814. For gases, see p. 214.

For the specific gravities of the metals, there are usually two values given. The low figures are usually those of cast metals, the high ones of metal either finely rolled or drawn into fine wire.

SPECIFIC GRAVITIES AND UNIT WEIGHTS OF SOLIDS AND LIQUIDS  
*Continued*

Substance	Average sp. gr. (water = 1)	Average weight (lb. per cu. ft.)
Wax (bees) . . . . .	0 97	60 5
Wood: dry, seasoned:		
Ash, white . . . . .	0.55-0.62	38 0
Birch . . . . .	0.32-0 59	41 0
Cedar, white . . . . .	0.32-0 42	28 0
red . . . . .	0.48-0 57	35 0
Cherry . . . . .	0.60-0.90	42 0
Chestnut . . . . .	0 44-0 66	41 0
Elm . . . . .	0 54-0.74	35 0
Ebony . . . . .	1.11-1 33	76 0
Fir, Douglas . . . . .	0.45-0.50	20 0
Hemlock . . . . .	0 36 0 42	25 0
Hickory . . . . .	0.70-0 93	53 0
Mahogany, Spanish . . . . .	0 85	53 0
Honduras . . . . .	0 56-0 66	35 0
Maple . . . . .	0.53-1 00	49 0
Oak, live . . . . .	.....	59 0
white . . . . .	0 8	48 0
black, jack, etc . . . . .	0 30-0 75	35-45
Pine, white . . . . .	0 35-0 50	25 0
yellow, Northern . . . . .	0 37 0 61	34 0
Southern . . . . .	.....	45 0
Poplar (cottonwood) . . . . .	0.35-0 50	33 0
Spruce . . . . .	0 31 0 40	25 0
Sycamore . . . . .	0.40-0 60	37 0
Walnut . . . . .	0 64-0 70	37 0
Yttrium . . . . .	3 8	237 0
Zinc . . . . .	7 15	446 0
(molten (660°C) . . . . .	6 81	405 0
Zirconium . . . . .	6 25	390 0

DENSITY OF METALS AT HIGH TEMPERATURES<sup>1</sup>

Degrees, C	Tin	Mag- nesium	Alumi- num	Cop- per	Bronze		
					92-8	82-18	71 29
20	.....	1 739	.....	8 93	8 83	8.89	8.92
600	.....	1.650	.....	.....	8.55	8 55	.....
700	6.68	1.544	2 38	.....	8.47	8.49	8 49
800	6.61	.....	2 35	8 64	8.41	.....	8.14
900	6.57	.....	2.32	8.46	.....	.....	.....
1000	.....	.....	.....	8 31	.....	7 95	7 90
1100	.....	.....	.....	7.98	7 90	7 83	7.70
1200	.....	.....	.....	7.83	7 79	7 71	7.68

<sup>1</sup> Recalculated from K. BORNEMANN and F. SAUERWALD's results, *Ztsch. Metallkunde*, April, 1922, p 145. All metals but bismuth expand on melting.

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## PROPERTIES OF WATER<sup>1</sup>

Temperature, deg. F.	Weight in pounds per cubic foot in vacuo	Relative volume	Temperature, deg. F.	Weight in pounds per cubic foot in vacuo	Relative volume
32.0	62.418	1.00014	100	62.02	1.00656
39.1	62.427	1.00000	120	61.74	1.01113
50.0	62.41	1.00027	140	61.38	1.01706
60.0	62.37	1.00092	160	60.98	1.02373
62.0	62.355	1.00115	180	60.55	1.03100
70.0	62.30	1.00200	200	60.12	1.03837
80.0	62.23	1.00316	210	59.87	1.04271
90.0	62.13	1.00480	212	59.83	1.04340

For sea water, multiply the above by 1.026. One U. S. gallon of water at 62°F. weighs 8.3356 lb. Water freezes at 32°F.: is at its maximum density at 39.1°F., British standard for sp. gr., 62°F.; boiling point at sea-level, 212°F.

<sup>1</sup>Determinations by the Bureau of Standards.

## TABLE FOR WATER IN AIR<sup>1</sup>

The following table will give the amount of water weighed in air with brass weights necessary to fill a liter flask to the 1000 cc mark when the air and water are at the same temperature.

Temperature of water	Apparent weight	Temperature of water	Apparent weight
15	998.05	24	996.29
16	997.90	25	996.04
17	997.74	26	995.79
18	997.56	27	995.52
19	997.38	28	995.24
20 (standard)	997.18	29	994.96
21	996.97	30	994.66
22	996.76	31	994.46
23	996.53	32	994.06

<sup>1</sup> Bur. Standards, *Circ.* No. 19.

## DENSITIES OF MERCURY<sup>1</sup>

Temperature deg. F.	Pounds per cubic inch	Temperature deg. F.	Pounds per cubic inch	Temperature deg. F.	Pounds per cubic inch
0	0.4928	40.0	0.4907	80	0.4888
10	0.4923	50.0	0.4903	90	0.4883
20	0.4918	58.1	0.4899	100	0.4878
30	0.4913	60.0	0.4898	110	0.4873
32	0.4912	70.0	.....	.....	.....

Temperature deg. C.	Grams per cc.	Temperature deg. C.	Grams per cc.	Temperature deg. C.	Grams per cc.
-20	13.6450	40	13.4973	100	13.3518
-10	13.6202	50	13.4729	150	13.233
0	13.5955	60	13.4486	200	13.068
10	13.5708	70	13.4243	250	12.998
20	13.5462	80	13.4001	300	12.881
30	13.5217	90	13.3759	.....	.....

<sup>1</sup> ELLENWOOD'S "Steam Charts."

KIRBY'S TABLE OF WEIGHTS OF ORE IN PLACE<sup>1</sup>

Material	Weight per cubic foot		Cubic feet per ton	
	Theoretically, <sup>2</sup> pounds	Practically, pounds	Theoretically <sup>2</sup>	Practically
Galena.....	465	426	4.3	4.7
Pyrite.....	313	280	6.4	7.0
Blende.....	250	235	8.0	8.5
Hematite.....	303	267	6.6	7.5
Limonite.....	238	213	8.4	9.4
Dolomite.....	175	160	11.4	12.5
Limestone, andesite, syenite.....	168	154	11.9	13.0
Vein quartz, granite and granitic rocks.....	168	148	11.9	13.5
Clay, quartz, porphyry, trachytes, rhyolites.....	163	136	12.3	14.5
Vein quartz, with 15 per cent. galena.....	187	164	10.7	12.2
Vein quartz, with 15 per cent. pyrites.....	180	160	11.1	12.5
Vein quartz, with 10 per cent. hematite.....	170	155	11.4	12.9

<sup>1</sup> R. H. RICHARDS, "Ore Dressing, Vol. II."<sup>2</sup> Calculated from specific gravity of pure unaltered specimens.

MCDONALD'S TABLE OF WEIGHTS OF ORE

Material	Weight per cubic foot		Cubic feet per ton	
	In place, pounds	Broken, pounds	In place	Broken
Granite and porphyry.....	170	97	11.8	20.6
Gneiss.....	168	96	11.9	20.8
Greenstone and trap.....	187	107	10.7	18.7
Limestone.....	168	96	11.9	20.8
Slate.....	175	95	11.4	21.1
Quartz.....	165	94	12.1	21.3
Sandstone.....	151	86	13.2	23.3
Earth in bank.....	111	.....	18.0	.....
Earth dry and loose.....	.....	74	.....	27.0
Clay.....	118	.....	17.0	.....
Sand.....	80	.....	25.0	.....

WEIGHT OF ROCK AND SAND<sup>1</sup>

	Cubic feet per ton	Weight in pounds per cubic foot
Sulphide ore in place.....	11 to 13	154 to 182
Sulphide ore broken.....	15 to 18	111 to 133
Oxidized ore in place.....	14 to 18	111 to 143
Oxidized ore broken.....	22 to 24	81 to 91
Mill tailing <sup>2</sup> (sp. gr. 2.7)		
Sand collected under water.....	21.5	93.0
Transferred sand (before leaching).....	26.0	77.0
Leached sand (after transferring).....	24.0	83.3

<sup>1</sup> From MACFARREN'S "Cyanide Practice." "Mining and Scientific Press," San Francisco, Calif<sup>2</sup> W. A. CALDECOTT, *Journ. Chem., Met. and Min. Soc. of S.A.*, Oct., 1910.

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## DENSITY AND HARDNESS OF MINERALS<sup>1</sup>

	Specific gravity	Hardness
<i>Acids and oxides:</i>		
Arsenous acid, As <sub>2</sub> O <sub>3</sub> ...	3.69-3.70	1.5
Boric acid, B(OH) <sub>3</sub> ...	1.48	1.0
Titanic acid, anatase, TiO <sub>2</sub> ...	3.88	5.5-6.0
brookite, TiO <sub>2</sub> ...	4.14	5.5-6.0
rutile, TiO <sub>2</sub> ...	4.28	6.0-6.5
Bauxite, Al <sub>2</sub> O <sub>3</sub> ·2H <sub>2</sub> O...	2.63-2.80	
Corundum, Al <sub>2</sub> O <sub>3</sub> .....	3.90-4.02	9.0
Cuprite, Cu <sub>2</sub> O...	5.99	3.75
Diaspore, Al(OH) <sub>3</sub> ·Al <sub>2</sub> O <sub>3</sub> ...	3.37	6.5
Tin oxide (cassiterite), SnO <sub>2</sub> ...	6.30-7.10	6.5
Melaconite (black copper), CuO	6.20-6.30	3.0-4.0
Hematite, Fe <sub>2</sub> O <sub>3</sub> .....	4.54-5.28	6.0
Magnetite, Fe <sub>3</sub> O <sub>4</sub> .....	4.94-5.18	5.5
Ferric oxide (hydrates) limonite.....	3.60-4.00	5.5
Ice at 0°C.....	0.92	
Magnesia (periclase), MgO	3.67	6.0
Magnesia (hydrated, brucite), Mg(OH) <sub>2</sub>	2.35	2.5
Manganese oxide, braunite, .....	4.75	6.0-6.5
hausmannite, Mn <sub>3</sub> O <sub>4</sub>	4.72	5.0-5.5
pyrolusite, MnO <sub>2</sub>	4.82-4.97	2.0
Silica, agate, SiO <sub>2</sub>	2.58-2.62	6.0
quartz, SiO <sub>2</sub>	2.65	7.0
Opal (hydrated silica)	2.03-2.09	5.5-6.5
Uranium oxide (pitchblende)...	6.01-8.07	5.5
Zincite, ZnO	5.57	4.0-4.5
<i>Aluminates:</i>		
Spinel, MgO·Al <sub>2</sub> O <sub>3</sub> .....	3.55	8.0
Anorthite, Ca <sub>2</sub> Al <sub>2</sub> Si <sub>2</sub> O <sub>10</sub> ...	2.7	6.0-7.0
<i>Antimonides:</i>		
Breithauptite, NiSb...	7.54	5.5
Antimonite, Sb <sub>2</sub> S <sub>3</sub> .....	4.57	2.5
<i>Arsenides:</i>		
Cobalt arsenide, smaltite, (Co,Ni)As <sub>2</sub> ....	6.11	5.5
Copper arsenide, domcykite, Cu <sub>3</sub> As.....	7.75	3.0-3.5
Nickel arsenide, mecohlite, NiAs	7.72	5.5
<i>Borates:</i>		
Boracite, Mg <sub>7</sub> Cl <sub>2</sub> B <sub>10</sub> O <sub>30</sub>	2.91-2.97	5.0-7.0
Borax, Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·10H <sub>2</sub> O	1.72	2.0
<i>Bromides:</i>		
Silver bromide, AgBr	5.80-6.00	2.0-3.0
<i>Carbonates:</i>		
Aragonite, CaCO <sub>3</sub> ...	2.93-2.94	3.5-4.0
Azurite, 3Cu <sub>2</sub> (C <sub>2</sub> O <sub>7</sub> )·7H <sub>2</sub> O....	3.70-3.83	4.0
Calcite, CaCO <sub>3</sub> .....	2.70-2.73	3.0-3.65
Cerussite, PbCO <sub>3</sub>	6.57	3.25
Dolomite, MgCa(CO <sub>3</sub> ) <sub>2</sub>	2.83-2.94	3.75
Malachite, Cu <sub>2</sub> (CO <sub>3</sub> ) <sub>2</sub> ·H <sub>2</sub> O...	3.93	3.5
Magnesite, MgCO <sub>3</sub> .....	3.0	3.5-4.5
Siderite, FeCO <sub>3</sub>	3.83-3.88	3.5-4.0
Smithsonite, ZnCO <sub>3</sub> ...	4.30-4.45	5.0
Stroniantite, SrCO <sub>3</sub> .....	3.60-3.71	3.5-4.0
Witherite, BaCO <sub>3</sub> .....	4.28	3.5
<i>Chlorides:</i>		
Atacamite, Cu <sub>2</sub> (OH) <sub>2</sub> Cl.....	3.70	3.0-3.5
Calomel, Hg <sub>2</sub> Cl <sub>2</sub>	6.48	1.0-2.0
Carnallite, KMgCl <sub>3</sub> ·6H <sub>2</sub> O.....	1.6	1.0
Cerargyrite, AgCl	5.31-5.43	1.5
Rock salt, NaCl	2.26	2.5
Sylvite, KCl	1.90-2.00	2.0
<i>Chromates:</i>		
Lead chromate, PbCrO <sub>4</sub>	5.90-6.10	2.5-3.0
Chromite, FeCr <sub>2</sub> O <sub>4</sub> ...	4.32-4.50	5.5

<sup>1</sup> See also table on p. 213.



	Specific gravity	Hardness
<b>Fluorides:</b>		
Cryolite, $\text{Na}_3\text{AlF}_6$ . . . . .	2.96	2.5
Fluorite, $\text{CaF}_2$ . . . . .	3.14-3.19	4.0
<b>Molybdates:</b>		
Wulfenite, $\text{PbMoO}_4$ . . . . .	6.95	3.0
<b>Niobates and Tantalates:</b>		
Fergusonite, Y, Er, Ce, Nb, Ta, O . . . . .	5.84	5.5-6.0
Niobite, $\text{FeNb}_2\text{O}_6$ . . . . .	5.60-6.00	6.0
Samaraskite . . . . .	5.54	5.0-6.0
Tantalite, $\text{FeTa}_2\text{O}_6$ . . . . .	7.03	6.0
<b>Nitrates:</b>		
Salt peter, $\text{KNO}_3$ . . . . .	1.94	2.0
<b>Phosphates:</b>		
Apatite . . . . .	2.90-3.20	5.0
Autunite . . . . .	3.57	2.0-2.5
Monazite (Ce, La) $\text{PO}_4$ . . . . .	5.00-5.09	5.2
Pyromorphite, $\text{Pb}_5\text{Cl}(\text{PO}_4)_3$ . . . . .	6.59-7.05	3.5-4.0
Turquoise . . . . .	2.52-2.80	6.0
Chalcophite . . . . .	3.40-3.60	2.0-2.5
<b>Silicates:</b>		
Albite . . . . .	2.60-2.62	6.0
Amphibole . . . . .	2.92-3.59	5.5
Andalousite, $\text{Al}_2\text{SiO}_5$ . . . . .	3.14-3.16	7.5
Augite . . . . .	3.20-3.50	5.0-6.0
Emerald (beryl) . . . . .	2.67-2.75	7.5-8.0
Epidote . . . . .	3.46	6.5
Feldspar, orthoclase . . . . .	2.50-2.59	6.0
albite . . . . .	2.60-2.62	6.0
oboloclase . . . . .	2.61-2.64	6.0
andesite . . . . .	2.67-2.68	
labradorite . . . . .	2.70-2.72	6.0
anorthite . . . . .	2.75	
Gadolinite, $\text{Be}_2\text{FeY}_2\text{Si}_2\text{O}_{10}$ . . . . .	4.23-4.33	6.5-7.0
Granite . . . . .	3.42-4.20	
Hornblende . . . . .	2.90-3.40	5.0-6.0
Hypersthene (Fe, Mg) $\text{SiO}_3$ . . . . .	3.36-3.42	5.0-6.0
Idocrase . . . . .	3.29-3.43	6.5
Jadeite, $\text{NaAl}(\text{SiO}_3)_2$ . . . . .	3.28-3.35	6.5-7.0
Lapis-lazuli . . . . .	2.50-3.04	5.0-5.5
Peridot . . . . .	3.33-3.41	6.5-7.0
Phenacite, $\text{Be}_2\text{SiO}_4$ . . . . .	2.96	7.5-8.0
Olivine (Mg, Fe) $\text{SiO}_3$ . . . . .	3.30-3.50	6.0-7.0
Mica . . . . .	2.70-3.10	2.0-2.5
Pyroxene, diopside . . . . .	3.32	4.0-6.0
augite . . . . .	3.30	5.5
hedenbergite . . . . .	3.50	
Quartz, $\text{SiO}_2$ . . . . .	2.65	7.0
Rhodonite . . . . .	3.64	5.5-6.5
Serpentine . . . . .	2.6	3.0-4.0
Sillimanite, $\text{Al}_2\text{OSiO}_4$ . . . . .	3.24	7.5
Thorite, $\text{ThSiO}_4$ . . . . .	4.19-5.22	4.5-5.0
Willemite, $\text{Zn}_2\text{SiO}_4$ . . . . .	4.01	5.0
Wollastonite, $\text{CaSiO}_3$ . . . . .	2.80-2.90	4.5-5.0
Zircon, $\text{ZrSiO}_4$ . . . . .	4.04-4.67	7.5
<b>Hydrated silicates:</b>		
Calamine, $\text{Zn}_2(\text{OH})_2\text{SiO}_3$ . . . . .	3.35-3.50	5.0
Chrysocolla, $\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$ . . . . .	2.00-2.20	3.5
Halloysite . . . . .	1.92-2.12	
Kaolin . . . . .	2.5	1.0
Magnesite, $\text{H}_2\text{Mg}_3\text{Si}_3\text{O}_{10}$ . . . . .	1.80-2.20	2.0-2.5
Pyrophyllite, $\text{HAl}(\text{SiO}_3)_2$ . . . . .	2.78	1.5
Talc . . . . .	2.71	1.0
Thomsonite . . . . .	2.38	5.0-5.5
<b>Silicoborate:</b>		
Tourmaline . . . . .	3.04-3.20	7.0-7.5
<b>Silicochlorides:</b>		
Sodalite . . . . .	2.38-2.42	5.5-6.0

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	Specific gravity	Hardness
<i>Silicofluorides:</i>		
Leucophane.....	2.97	4.0
Mica.....	2.71-3.13	2.0-3.0
Topaz.....	3.51-3.58	8.0
<i>Siliconiobate:</i>		
Wöhlerite.....	3.41	5 5-6.0
<i>Sulphates:</i>		
Anglesite, $\text{PbSO}_4$ .....	6.26-6.30	3.0
Anhydrite, $\text{CaSO}_4$ .....	2.90-2.96	3.0-3.5
Barite, $\text{BaSO}_4$ .....	4.48-4.72	3.0
Celestine, $\text{SrSO}_4$ .....	3.92-3.96	3.0-3.5
Epsomite, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ .....	1.75	2.0-2.5
Glauberite, $\text{Na}_2\text{SO}_4$ .....	2.64-2.85	
Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ .....	2.33	2.0
Kainit, $\text{MgSO}_4 \cdot \text{KCl} \cdot 3\text{H}_2\text{O}$ .....	2.1	2.5
<i>Sulphides:</i>		
Argentite, $\text{Ag}_2\text{S}$ .....	7.24	2.5
Bismuthinite, $\text{Bi}_2\text{S}_3$ .....	6.40	2.0
Blende (sphalerite), $\text{ZnS}$ .....	4.09	3.5-4.0
Bornite, $\text{Cu}_3\text{FeS}_4$ .....	4.40-5.50	3.0
Chalcocite, $\text{Cu}_2\text{S}$ .....	5.78	2.75
Chalcopyrite, $\text{CuFeS}_2$ .....	4.17	4.0-4.2
Cinnabar, $\text{HgS}$ .....	8.12-8.20	2.5
Erubescite, $\text{Cu}_3\text{FeS}_4$ .....	5.05	3.0
Galena, $\text{PbS}$ .....	7.26-7.60	2.75
Greenockite, $\text{CdS}$ .....	4.99	3.0-3.5
Marcasite, $\text{FeS}_2$ .....	4.77-4.86	6.0-6.5
Millerite, $\text{NiS}$ .....	5.65	3.5
Molybdenite, $\text{MoS}_2$ .....	4.94	1.5
Orpiment, $\text{As}_2\text{S}_3$ .....	3.45	1.75
Pyrite, $\text{FeS}_2$ .....	4.85-5.04	6.0
Pyrrhotite, $\text{FeS}$ .....	4.62	4.0
Realgar, $\text{AsS}$ .....	3.04	2.0
Stibnite, $\text{Sb}_2\text{S}_3$ .....	4.62	2.0
Sphalerite, $\text{ZnS}$ .....	4.09	3.5-4.0
<i>Sulphantimonides:</i>		
Bournonite, $\text{PbCuSbS}_3$ .....	5.75-5.83	2.5-3.0
Jamesonite, $\text{PbFeSbS}_4$ .....	5.61	2.5
Pyrrargyrite, $\text{Ag}_3\text{SbS}_3$ .....	5.86	2.5
<i>Sulpharsenides:</i>		
Cobaltite, $\text{CoAsS}$ .....	6.26-6.37	5.5
Enargite, $\text{Cu}_3\text{AsS}_4$ .....	4.36	3.0
Mispickel, $\text{FeAsS}$ .....	5.22-6.07	5.5-6.0
Proustite, $\text{Ag}_3\text{AsS}_3$ .....	5.50	2.0-2.5
<i>Tellurides:</i>		
Nagyagite, $\text{Au, Pb, Sb, Te, S}$ .....	6.68-7.20	1.0-1.5
Tetradymite, $\text{Bi, Te, S}$ .....	7.41	1.5-2.0
Petzite, $(\text{Ag, Au})_2\text{Te}$ .....	8.83	2.5-3.0
Sylvanite, $\text{AuAgTe}_4$ .....	8.28	2.0
<i>Titanates:</i>		
Ilmenite, $\text{FeTiO}_3$ .....	4.89	5.0-6.0
<i>Tungstates:</i>		
Scheelite, $\text{CaWO}_4$ .....	6.07	4.5-5.0
Wolframite, $(\text{Fe, Mn})\text{WO}_4$ .....	7.14-7.36	5.0-5.5
<i>Vanadates:</i>		
Descloizite.....	5.84	3.0-5.0
Vanadinite, $\text{Pb}_3\text{Cl}(\text{VO}_4)_3$ .....	6.66-7.23	3.0
<i>Combustibles:</i>		
Anthracite.....	1.34-1.46	
Asphalt.....	0.83-1.16	
Bituminous.....	1.28-1.36	
Lignite.....	1.10-1.35	

The Principal Concentrating Ores and Gangues<sup>1</sup>

	Specific gravity	Hardness
<b>Lead:</b>		
Galena.....	7.26-7.60	2.0-3.0
Cerussite.....	6.57	3.75
Anglesite.....	6.26-6.30	3.0
<b>Copper:</b>		
Melaconite.....	6.0	3.0-4.0
Cuprite.....	3.09-4.02	
Chalcocite.....	5.78	2.75
Bornite.....	4.40-5.50	3.0
Chalcopyrite.....	4.17	3.5-4.0
Malachite.....	3.93	3.5-4.0
Chrysocolla.....	2.00-2.20	2.0-4.0
Tetrahedrite, 4 Cu <sub>2</sub> S Sb <sub>2</sub> S <sub>3</sub> .....	4.4-5.1	3.0-4.0
<b>Iron:</b>		
Mispickel.....	5.22-6.07	5.5-6.0
Magnetite.....	4.94-5.18	5.5-6.5
Pyrite.....	4.85-5.04	6.0-6.5
Marcasite.....	4.77-4.86	6.0-6.5
Pyrrhotite.....	4.62	4.0
<b>Zinc:</b>		
Franklinite.....	5.07-5.22	6.0
Smithsonite.....	4.30-4.45	5.0
Sphalerite.....	4.09	3.5-4.0
Willemite.....	4.01	5.0
<b>Gangues:</b>		
Barite (heavy spar).....	4.48-4.72	3.0-3.5
Manganese garnet.....	1.10-4.50	7.0
Iron garnet.....	3.90-4.40	7.0
Lime garnet.....	3.40-3.50	7.0
Fluorite (fluorspar).....	3.14-3.19	4.0
Anhydrite (gypsum).....	2.90-2.96	1.5-2.0
Dolomite.....	2.83-2.94	3.5-4.0
Quartz.....	2.50-2.80	7.0
Calcite.....	2.70-2.73	3.0
Kaolinite.....	2.40-2.60	1.0
Hematite.....	4.50-5.30	5.5-6.5
Serpentine.....	2.6	3.0-4.0
Spinel.....	3.50-3.60	8.0
Talc.....	2.50-2.80	1.0
Cyanite, Al <sub>2</sub> SiO <sub>5</sub> .....	3.56-3.67	5.0-7.0
Muscovite, KAl(SiO <sub>3</sub> ) <sub>2</sub> , Common mica.....	2.76-3.0	2.0-2.5
<b>Miscellaneous:</b>		
Hornblende.....	2.90-3.50	5.0-6.0
Monazite.....	5.0	5.2
Pitchblende.....	6.4	5.5
Rutile.....	4.20-4.30	6.0-6.5
Thorianite.....	8.00-9.70	7.0
Thorite.....	4.6	
Wolframite.....	7.10-7.90	5.0-5.5
Graphite.....	2.09-2.23	

<sup>1</sup> From MEGRAW'S "Practical Data for the Cyanide Plant." For a longer table, based on acid radicals, see p. 210.

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## SPECIFIC GRAVITY AND ABSOLUTE WEIGHT OF GASES

Gas	Formula	Molecular wt. (O=16)	Weight of 1 liter in grams, N.P.T.	Sp. gr. (air = 1)	Wt. of 1 cu. ft. in pounds N.P.T.
Acetylene..	C <sub>2</sub> H <sub>2</sub>	26.015	1.173	0.9093	0.07323
Air.....			1.2929	1.0000	0.08071
Aldehyde..	C <sub>2</sub> H <sub>4</sub> O	44.031	1.9811	1.5325	0.12368
Ammonia..	NH <sub>3</sub>	17.032	0.7710	0.5964	0.04813
Alcohol, amyl ..	C <sub>5</sub> H <sub>11</sub> OH	88.092	4.0696	3.1479	0.25406
Alcohol, ethyl ..	C <sub>2</sub> H <sub>5</sub> OH	46.046	2.0862	1.6137	0.13024
Alcohol, methyl ..	CH <sub>3</sub> OH	32.031	1.4483	1.1202	0.09042
Argon.....	A	39.91	1.7832	1.3792	0.11132
Arsine.....	AsH <sub>3</sub>	77.983	3.480	2.6916	0.21593
Benzene.....	C <sub>6</sub> H <sub>6</sub>	78.046	3.5821	2.7708	0.22362
Boron chloride	BCl <sub>3</sub>	117.194	5.09	3.937	0.3177
Boron fluoride	BF <sub>3</sub>	67.82	2.99	2.312	0.1867
Bromine.....	Br <sub>2</sub>	159.82	7.1437	5.5258	0.44597
Butane.....	C <sub>4</sub> H <sub>10</sub>	58.077	2.673	2.075	0.1654
Carbon dioxide	CO <sub>2</sub>	44.000	1.9769	1.5290	0.12341
Carbon monoxide.	CO	28.000	1.2504	0.9671	0.07806
Carbonyl chloride..	COCl <sub>2</sub>	96.916	4.47	3.457	0.2791
Carbonyl sulphide	COS	60.065	2.721	2.104	0.16987
Chlorine.....	Cl <sub>2</sub>	70.916	3.214	2.4589	0.20064
Chlorine dioxide..	ClO <sub>2</sub>	67.458	3.0192	2.3352	0.18848
Chlorine monoxide.	Cl <sub>2</sub> O	86.916	3.89	3.0079	0.24284
Cyanogen.....	C <sub>2</sub> N <sub>2</sub>	52.016	2.335	1.7983	0.14577
Ethane.....	C <sub>2</sub> H <sub>6</sub>	30.046	1.3566	1.0492	0.08470
Ethylene.....	C <sub>2</sub> H <sub>4</sub>	28.031	1.2604	0.9749	0.07869
Fluorine.....	F <sub>2</sub>	38.00	1.695	1.313	0.10588
Helium.....	He	4.00	0.1785	0.1381	0.01114
Hydrobromic acid	HBr	80.924	3.6445	2.8188	0.21506
Hydrochloric acid	HCl	36.466	1.6392	1.2679	0.10233
Hydrocyanic acid..	HCN	27.016	1.226	0.9483	0.07654
Hydrofluoric acid..	HF	20.008	0.9220	0.71318	0.05756
Hydroiodic acid..	HI	127.940	5.7891	4.477	0.36140
Hydrogen.....	H <sub>2</sub>	2.0154	0.08988	0.06951	0.00561
Hydrogen arsenide	AsH <sub>3</sub>	77.983	3.4589	2.6753	0.21593
Hydrogen phosphide	PH <sub>3</sub>	34.047	1.5293	1.1829	0.09547
Hydrogen selenide..	H <sub>2</sub> Se	81.254	3.628	2.80629	0.2265
Hydrogen sulphide	H <sub>2</sub> S	34.080	1.539	1.1904	0.09607
Hydrogen telluride	H <sub>2</sub> Te	129.515	5.80	4.486	0.3621
Iodine.....	I <sub>2</sub>	253.864	11.271	8.7183	0.70363
Krypton.....	Kr	82.9	3.708	2.8682	0.23148
Mercury.....	Hg	200.61	9.0210	6.9785	0.56317
Methane.....	CH <sub>4</sub>	16.031	0.7168	0.5544	0.04475
Methylamine.....	CH <sub>3</sub> NH <sub>2</sub>	31.0465	1.396	1.0797	0.08715
Methyl chloride..	CH <sub>3</sub> Cl	50.481	2.3076	1.7848	0.14406
Methyl ether.....	(CH <sub>3</sub> ) <sub>2</sub> O	46.046	2.1098	1.6361	0.13171
Methyl fluoride	CH <sub>3</sub> F	31.023	1.5452	1.19501	0.09646
Neon.....	Ne	20.2	0.9002	0.69634	0.05620
Nitric oxide.....	NO	30.008	1.3402	1.03669	0.08367
Nitrous oxide.....	N <sub>2</sub> O	44.016	1.977	1.529	0.12342
Nitrogen (chem) ..	N <sub>2</sub>	28.016	1.2505	0.96720	0.07835
Nitrogen (atmospheric)			1.2568	0.97208	0.07846
Nitrogen tetroxide	N <sub>2</sub> O <sub>4</sub>	88.064	4.1133	3.18178	0.25679
Nitrogen tetroxide ..	NO <sub>2</sub>	44.032	2.0567	1.59092	0.12840
Nitrosyl chloride	NOCl	65.466	2.992	2.3119	0.18678
Oxygen.....	O <sub>2</sub>	32.000	1.4290	1.10527	0.08920
Phosphine.....	PH <sub>3</sub>	34.047	1.5294	1.18285	0.09548
Phosphorus.....	P <sub>4</sub>	124.096	5.6318	4.35639	0.35158
Propane.....	C <sub>3</sub> H <sub>8</sub>	44.062	2.020	1.5625	0.12610
Propylene.....	C <sub>3</sub> H <sub>6</sub>	42.046	1.8783	1.45293	0.11726
Radium emanation	Ra	222.00	9.73	7.524	0.60742
Silicon fluoride..	SiF <sub>4</sub>	104.06	4.684	3.6049	0.29093
Sulphur dioxide..	SO <sub>2</sub>	64.065	2.9269	2.26382	0.18272
Xenon.....	Xe	130.2	5.851	3.7524	0.36527
Water.....	H <sub>2</sub> O	18.015	0.8063	0.6237	0.05034

The column headed Weight of 1 liter in grams, etc., is mainly based upon the tables in "Annuaire pour 1914, Bureau des Longitudes" and in the "Critical Tables" published by the International Research Council and associates. Other data are compiled from various sources. There is a wide variation in the results for these constants, even between the work of two supposedly equally qualified workers. For that reason I have, in several instances, cut out some of the last decimal places. In part this variation is caused by the effect of surface condensation of gas films on the apparatus worked with and in part it is probably due to the shape of the vessel itself, as set forth by Morley in 1895.

The determination of these constants for gases is by no means a simple problem. So far as possible, the values are those obtained experimentally, and are not simply calculated from atomic weights. In the cases of such substances as mercury, water, etc., the values at 0° and 29.92 in. of mercury pressure are purely theoretical. The experiments for the determination of the constants have been made at higher temperatures and the values in the table calculated from the equation  $pv = RmT$ .

If a gas be expanded or compressed so quickly that no heat is either absorbed or given off, then  $pv^{1.408} = k$ .

In the above equation,  $p$  represents pressure;  $v$  volume;  $m$ , mass;  $T$ , degrees absolute; and  $R$ , the so-called gas constant. It is obvious, that given any mass of gas, if the pressure, volume, and temperature are known,  $R$  can be calculated for that mass, and having been calculated, if the mass be unchanged, but the pressure or volume or temperature, or any two or all of them, be altered, if two of the three are known the other may be calculated. But to take a special case, if masses in grams equal to the molecular weights of various gases be taken,  $R$  is almost uniform for all gases. This value is the so-called gas constant. If  $p$  be taken in kilogram per sq. cm.,  $v$  in liters and  $T$  in degrees absolute equal to  $C^{\circ} + 273$ , then  $R$  will be closely 82.07, which M. D. BERTHELOT gives as the value for a perfect gas. Obviously, there is a gas constant, but a different one in the ft.-lb.- $K^{\circ}$  notation. A gram-molecule of gas is variously stated at from 22,318 cc. to 22,412 cc., the latter being the Smithsonian Tables value. Berthelot gives it at 22,380 cc.

The number of molecules per cubic centimeter of gas under standard conditions is about  $27.09 \times 10^{18}$ .

### Critical Temperatures and Pressures<sup>1</sup>

The critical temperature of a gas is that temperature above which no pressure suffices to produce a liquid. The pressure at which a gas at the critical temperature begins to become a liquid is known as the critical pressure:

<sup>1</sup> "Annuaire par 1914, Bureau des Longitudes."

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Substance	Critical temperature, deg. C	Critical pressure, atmos.	Critical density calculated g. per cm. <sup>3</sup>
<b>Elements:</b>			
Argon.....	-122	48	0.531
Bromine.....	302		
Chlorine.....	144.0	76.1	0.573
Helium.....	-267.9	2.26	0.0693
Hydrogen.....	-239.9	12.8	0.0310
Iodine.....	553		
Krypton.....	-63	54	0.78
Mercury.....	>1550	>200	4-5
Neon.....	-228.7	25.9	0.484
Nitrogen.....	-147.1	33.5	0.3110
Oxygen.....	-118.8	49.7	0.430
Sulphur.....	1040		
Xenon.....	16.6	58.2	1.155
Air.....	-140.7	37.2	0.35
<b>Inorganic compounds:</b>			
Amonia.....	132.4	111.5	0.235
Germanium chloride.....	277	38	
Hydrobromic acid.....	90	84	
Hydrochloric acid.....	51.4	81.6	0.42
Hydriodic acid.....	151	82	
Hydrogen sulphide.....	100.4	88.9	
Hydrogen selenide.....	138	88	
Nitric oxide, N <sub>2</sub> O.....	-94	65	0.52
Nitrogen peroxide, N <sub>2</sub> O <sub>4</sub> .....	158	99	
Nitrosyl chloride, NOCl.....	167		
Nitrous oxide, N <sub>2</sub> O.....	36.5	71.7	0.45
Phosphine, PH <sub>3</sub> .....	51	64	0.30
Phosphorus trichloride, PCl <sub>3</sub> .....	285.5		
Silicon fluoride, SiF <sub>4</sub> .....	-1.5	50	
Silicon hydride, SiH <sub>4</sub> .....	-3.5	48	
Silicon tetrachloride, SiCl <sub>4</sub> .....	221		
Sulphur dioxide, SO <sub>2</sub> .....	157	78	
Tin tetrachloride, SnCl <sub>4</sub> .....	318.7	37	0.742
Water.....	374.0	217.7	0.4
<b>Carbon compounds:</b>			
Acetone, C <sub>3</sub> H <sub>6</sub> O.....	235.0	47	0.268
Acetylene, C <sub>2</sub> H <sub>2</sub> .....	36	62	0.231
Benzene, C <sub>6</sub> H <sub>6</sub> .....	288.5	47.7	0.304
Butane, C <sub>4</sub> H <sub>10</sub> .....	153	36	
Carbon dioxide, CO <sub>2</sub> .....	31.1	73.0	0.460
Carbon disulphide, CS <sub>2</sub> .....	273	76	
Carbon monoxide, CO.....	-139	35	0.311
Carbon oxysulphide, COS.....	105	61	
Carbon tetrachloride, CCl <sub>4</sub> .....	283.1	45.0	0.558
Cyanogen, C <sub>2</sub> N <sub>2</sub> .....	128	59	
Ethane, C <sub>2</sub> H <sub>6</sub> .....	32.1	48.8	0.21
Ethylalcohol, C <sub>2</sub> H <sub>5</sub> OH.....	243.1	63.1	0.275
Ethylene, C <sub>2</sub> H <sub>4</sub> .....	9.7	50.9	0.22
Hydrocyanic acid, HCN.....	183.5	50	0.20
Methane, CH <sub>4</sub> .....	-82.5	45.8	0.162
Methylchloride, CH <sub>3</sub> Cl.....	143.1	65.8	0.37
Naphthalene, C <sub>10</sub> H <sub>8</sub> .....	468.2	39.2	
Pentane, C <sub>5</sub> H <sub>12</sub> .....	197.2	33.0	0.296
Phenol, C <sub>6</sub> H <sub>5</sub> OH.....	419	60.5	
Phosgene, CCl <sub>2</sub> O.....	182	56	0.52
Propane, C <sub>3</sub> H <sub>8</sub> .....	95.6	43	
Propylene, C <sub>3</sub> H <sub>6</sub> .....	92.3	45.0	
Toluene, C <sub>7</sub> H <sub>8</sub> .....	320.6	41.6	0.292

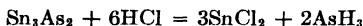
## How to Generate the Various Gases

**Acetylene.**—Best generated from calcium carbide and water ( $\text{CaC}_2 + 2\text{H}_2\text{O} = \text{Ca}(\text{OH})_2 + \text{C}_2\text{H}_2$ ). Can also be prepared by the incomplete combustion of coal gas, or by the action of acetylene bromide on alcoholic potash ( $\text{C}_2\text{H}_3\text{Br}_2 + 2\text{KOH} = \text{C}_2\text{H}_2 + 2\text{H}_2\text{O} + 2\text{KBr}$ ). Can also be bought compressed in cylinders.

**Ammonia.**—Best generated by the action of calcium oxide on ammonium chloride. Can be bought compressed in cylinders.

**Argon.**—Can be obtained by depriving air of oxygen with phosphorus, then absorbing the nitrogen by red-hot magnesium.

**Arsine.**—The gas may be obtained pure by the following reaction:



It is also formed when any arsenious compound comes into contact with nascent hydrogen, which reaction forms the basis for the well-known MARSH test. The other hydride of arsenic,  $\text{As}_2\text{H}_4$ , is a solid.

**Bromine.**—Best generated by heating the easily purchased liquid bromine.

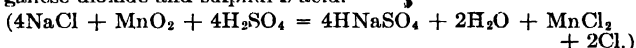
**Carbon Dioxide.**—Best made by the action of hydrochloric acid on marble or sulphuric acid on sodium carbonate. Can also be bought compressed.

**Carbon Monoxide.**—Best made pure by heating oxalic acid with concentrated sulphuric acid and absorbing the carbon dioxide in calcium hydrate emulsion:



Can also be made by passing  $\text{CO}_2$  over red hot coke or charcoal. This last reaction is not self-sustaining but requires considerable external heat.

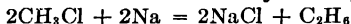
**Chlorine.**—Is readily generated from a mixture of salt, manganese dioxide and sulphuric acid.



It is also readily purchased compressed in cylinders.

**Cyanogen.**—This is easily made by heating mercuric cyanide. It is extremely poisonous.

**Ethane.**—Must be made from a methyl halide, as:



**Ethylene.**—Is best formed by treating an ethyl halide with potassium hydroxide ( $\text{C}_2\text{H}_5\text{Br} + \text{KOH} = \text{C}_2\text{H}_4 + \text{KBr} + \text{H}_2\text{O}$ ) or by treating ethyl alcohol with concentrated sulphuric acid.

**Hydrogen.**—Formed by the action of hydrochloric or sulphuric acid on metallic zinc, though the gas prepared in this way may contain hydrogen phosphide and arsine, so that it cannot be used for certain purposes. The Lane process produces hydrogen by passing steam over red-hot iron, and reducing the  $\text{Fe}_3\text{O}_4$  formed with water gas, the iron being again used to produce further quantities of hydrogen. It can also be produced by electrolytic methods (methods of Messerschmidt and of Bergius), and by the reactions  $\text{Ca}(\text{OH})_2 + \text{CO} = \text{CaCO}_3 +$

$\text{H}_2$  and  $\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2$ . It is said the hydrogen for Zeppelin inflation is made by starting the decomposition of acetylene electrically,  $\text{C}_2\text{H}_2 = 2\text{C} + \text{H}_2 + 47,800 \text{ cal.}$  Jaubert's method consists in preparing calcium hydride by passing hydrogen over calcium in an electric furnace,  $\text{Ca} + \text{H}_2 = \text{CaH}_2$ , then later generating the hydrogen where needed:  $\text{CaH}_2 + 2\text{H}_2\text{O} = \text{Ca(OH)}_2 + 2\text{H}_2$ . Strictly speaking, this is a method of transporting hydrogen rather than of generating it. Jaubert also has patented a hydrogenite mixture, 5 parts ferrosilicon, 12 parts caustic soda and 4 parts slacked lime.  $\text{Si} + 2\text{NaOH} + \text{Ca(OH)}_2 = \text{Na}_2\text{SiO}_3 + \text{CaO} + 2\text{H}_2\text{O}$ . Hydrogen may also be generated by the action of potassium or sodium on water.

**Hydrochloric Acid Gas.**—Given off by the action of concentrated sulphuric acid on aqueous hydrochloric acid.

**Hydrocyanic Acid Gas.**—This is formed by heating sulphuric acid and sodium cyanide. It is fearfully poisonous.

**Hydrogen Phosphide (Phosphine).**—This is formed when phosphorus is boiled with strong potash or caustic soda, or caustic lime ( $4\text{P} + 3\text{NaOH} + 3\text{H}_2\text{O} = 3\text{H}_2\text{NaPO}_2 + \text{PH}_3$ ). The gas as thus formed takes fire in contact with air, due to traces of  $\text{P}_2\text{H}_4$ . This compound can be removed by refrigerating mixtures and the resulting gas will not take fire spontaneously. These phosphorous compounds are very poisonous.

**Hydrogen Selenide.**—Formed by the action of dilute acids on aluminum selenide. This can be made by putting lump selenium in molten aluminum. A mask and gloves should be worn when making the selenide, as the mixture occasionally spatters badly. *The utmost precaution should be observed not to breathe the seleniuretted hydrogen.*

**Hydrogen Sulphide.**—Readily made by treating ferrous sulphide with hydrochloric acid, by the action of sulphuric acid on low-grade mattes, or by melting paraffin and sulphur together, or by heating sulphur and crude oil together.

**Hydrogen Telluride.**—Formed by the action of water on aluminum telluride. This is made by putting lumps of tellurium in molten aluminum. The slag which forms on the surface is aluminum telluride. Goggles should be worn when making this compound.

**Kakodyl.**— $[(\text{CH}_3)_2\text{As}]_2$ . This is formed by heating arsenious anhydride and potassium acetate in a closed retort. This is ordinarily a fetid, fuming liquid, violently, poisonous, and when pure, spontaneously inflammable.

**Methane.**—This is most easily prepared by heating a mixture of 2 parts sodium acetate, 2 parts potassium hydroxide and 3 parts quicklime ( $\text{NaC}_2\text{H}_3\text{O}_2 + \text{ROH} = \text{CH}_4 + \text{RNaCO}_3$ ). It can also be made by passing carbon disulphide and water vapor over red hot copper ( $\text{CS}_2 + 2\text{H}_2\text{O} + 6\text{Cu} = \text{CH}_4 + 2\text{Cu}_2\text{S} + 2\text{CuO}$ ).

**Nitric Anhydride.**—Prepared by passing dry chlorine over dry silver nitrate at  $95^\circ\text{C}$ .

**Nitrous Oxide.**—Obtained by heating ammonium nitrate crystals ( $\text{NH}_4\text{NO}_3 = \text{N}_2\text{O} + 2\text{H}_2\text{O}$ ). The reaction takes place at comparatively low temperatures.



**Nitrogen.**—Can be readily obtained by absorbing the oxygen from the air with phosphorus. In this case it contains about one-eightieth of its mass in argon and traces of helium, xenon, etc.

**Nitrogen Peroxide.**—Obtained by mixing two volumes of dry nitric oxide and one of oxygen together.

**Nitric Oxide.**—Obtained by the action of nitric acid on copper ( $3\text{Cu} + 8\text{HNO}_3 = 3\text{Cu}(\text{NO}_3)_2 + \text{H}_2\text{O} + \text{N}_2\text{O}_2$ ). The gas is colorless, but oxidizes with air to nitrogen peroxide, a reddish-brown gas.



**Oxygen.**—Is given off when manganese dioxide or potassium chlorate is heated, or, more safely, on ignition of a mixture of the two. Can also be made cheaply by electrolyzing dilute sulphuric-acid solution. Can be introduced into solution by hydrogen peroxide, sodium peroxide, fuming nitric acid, nitric acid, chloric acid, etc. The compressed gas is a common article of commerce.

**Phosphine.**—See hydrogen phosphide.

**Sulphur Dioxide.**—Formed by burning sulphur in air, or if wanted chemically pure, by the action of concentrated boiling sulphuric acid on copper ( $\text{Cu} + 2\text{H}_2\text{SO}_4 = \text{CuSO}_4 + 2\text{H}_2\text{O} + \text{SO}_2$ ).

**Sulphur Trioxide.**—This is most easily formed by roasting ferric sulphate.

### Principal Toxic Gases

The following list, from an address of PROF. I. GUARESCHI before the Associazione Chim. Industr. on June 14, 1915, at Turin, represents practice at that time. The list on p. 224 gives the gases in use at the end of the War.

Name	Formula	Sp gr.	Color	Discovered
Chlorine	$\text{Cl}_2$	2.45	Greenish yellow	Scheele 1774.
Hydrochloric acid	$\text{HCl}$	1.26	Colorless	Priestley, 1772.
Chlorine dioxide	$\text{ClO}_2$	1.28	Reddish yellow	H. Davy, 1815.
Bromine	$\text{Br}_2$	5.6	Red	Balard, 1823.
Hydrobromic acid	$\text{HBr}$			
Nitrogen dioxide	$\text{N}_2\text{O}_2$	1.039	Colorless	Priestley, 1772.
Nitrogen peroxide	$\text{N}_2\text{O}_4$	2.5	Red	Dulong, Gay-Lussac
Nitrosyl chloride	$\text{NOCl}$	2.33	Colorless	sac
Carbonyl chloride	$\text{COCl}_2$	3.5	Colorless	Gay-Lussac, 1848.
Carbon monoxide	$\text{CO}$	0.9674	Colorless	J. Davy, 1812.
Carbon dioxide	$\text{CO}_2$	1.524	Colorless	Lassone, Priestley
Hydrocyanic acid.	$\text{HCN}$	0.94	Colorless	V. Helmont
Cyanogen.	$(\text{CN})_2$	1.808	Colorless	(XVIIth).
Cyanogen chloride	$\text{CNCl}$	2.12	Colorless	Scheele, 1782.
Cyanogen bromide	$\text{CNBr}$	3.60	Colorless	Gay-Lussac, 1815.
Ammonia.	$\text{NH}_3$	0.59	Colorless	Berthollet, 1789.
Sulphureted hydrogen	$\text{H}_2\text{S}$	1.18	Colorless	Serullas, 1827.
Sulphur dioxide.	$\text{SO}_2$	2.247		Priestley, 1775.
Sulphur trioxide.	$\text{SO}_3$	2.74	Colorless	Scheele, 1777.
Phosphine	$\text{PH}_3$	1.178	Colorless	
Arsine	$\text{AsH}_3$	2.69	Colorless	XVth century.
				Gengembre, 1785.
				Scheele, 1775.

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FLUORINE GAS AND GASEOUS FLUORINE COMPOUNDS  
(All toxic)

Name	Formula	Sp. gr.	Color	Discoverer
Fluorine.....	$F_2$	1.264	Yellow	Moissan, 1886.
Hydrofluoric acid.....	$H_2F_2$	1.7	Colorless	Scheele, 1782
Boron fluoride.....	$BF_3$	2.312	Colorless	Gay-Lussac and Thenard, 1809.
Silicon fluoride.....	$SiF_4$	4.684	Colorless	Scheele, 1782.
Carbon fluoride.....	$CF_4$	3.09	Colorless	Moissan.
Fluoform.....	$CHF_3$	3.06	Colorless	Meslans.
Methyl difluoride.....	$CH_2F_2$	.....	Colorless	.....
Methyl fluoride.....	$CH_3F$	1.22	Colorless	Dumas and Peligot.
Phosphorus trifluoride.....	$PF_3$	3.05	Colorless	H. Davy.
Phosphorus pentafluoride.....	$PF_5$	4.5	Colorless	Thorpe.
Phosphoric oxyfluoride.....	$POF_3$	3.63	Colorless	Moissan.
Phosphorus dichlorotrifluoride.....	$PCl_2F_3$	5.41	Colorless	Pouleno.
Sulphur fluoride.....	$SF_6$	5.03	Colorless	Moissan and Lebeau.
Selenium fluoride.....	$SeF_6$	.....	Colorless	Prideaux, 1906.
Nitrosyl fluoride.....	$NOF$	1.68	Colorless	Gore, 1869.
Nitrile fluoride.....	$NO_2F$	2.24	Colorless	Moissan and Lebeau, 1905.
Thionyl fluoride.....	$SOF_2$	3.0	Colorless	Moissan and Lebeau, 1905.
Sulphur dioxide difluoride.....	$SO_2F_2$	3.55	Colorless	Moissan and Lebeau.
Ethyl fluoride.....	$C_2H_5F$	1.70	Colorless	Fremy.
Ethylene fluoride.....	$C_2H_4F_2$	.....	Colorless	Chabrie.
Propyl fluoride.....	$C_3H_7F$	2.16	Colorless	Meslans, 1894
Isopropyl fluoride.....	$C_3H_7F$	2.6	Colorless	Meslans, 1894.
Isobutyl fluoride.....	$C_4H_9F$	2.58	Colorless	Moissan.
Allyl fluoride.....	$C_3H_5F$	2.07	Colorless	Meslans.
Acetyl fluoride.....	$CH_3COF$	2.16	Colorless	Meslans.
Chromyl fluoride.....	$CrO_2F_2$	.....	Red	Olivieri, 1880.
Tungsten fluoride.....	$WF_6$	.....	Colorless	Roscoe.
Bromine pentafluoride.....	$BrF_5$	.....	Colorless	Lebeau, 1905.
Iodine pentafluoride.....	$IF_5$	.....	Colorless	Moissan, 1902.

On the subject of toxic gases, the following abstract of a lecture for Prof. Guareschi before the Turin Academy of Science on the properties of soda-lime, will also be of interest. (The abstract is from *Chemical Abstracts*)

## SLIGHTLY TOXIC AND THE RARE TOXIC GASES

Ozone.....	$O_3$	Carbon suboxide. . .	$(?)C_3O_2$
Chlorine suboxide.....	$Cl_2O$	Nickel carbonyl . . .	$Ni(CO)_4$
Nitrous oxide.....	$N_2O$	Diazomethane. . .	$CH_2N_2$
Nitrosyl dichloride.....	$NOCl_2$	Ammonia.....	$NH_3$
Hydriodic acid.....	$HI$	Boron chloride.....	$BCl_3$
Stibine.....	$SbH_3$	Boron hydride.....	$B_2H_6$
Hydrogen silicide.....	$SiH_4$	Acetylene.....	$C_2H_2$
Formaldehyde.....	$CH_2O$	Methyl chloride.....	$CH_3Cl$
Methyl carbamine.....	$C \equiv NCH_3$	Methyl ether . . .	$(CH_3)_2O$
Chromyl chloride.....	$CrO_2Cl_2$	Ethyl chloride.....	$C_2H_5Cl$
Hydrous phosphide.....	$P_2H_4$	Methyl phosphide...	$CH_3PH_2$
Carbon oxysulphide.....	$COS$	Methyl arsenide . . .	$AsH_2CH_3$
Thionyl chloride.....	$SOCl_2$	Dimethyl arsine. . .	$AsH(CH_3)_2$

Many reactions which take place with NaOH or KOH or lime either not at all or only at high temperatures occur at the ordinary temperature, and sometimes violently when soda-lime is employed. Further, soda-lime constitutes the most efficient agent to combat poisonous, irritating, or tear-producing gases, since it readily absorbs Cl, Br, halogen hydrides, CO<sub>2</sub>, SO<sub>2</sub>, COCl<sub>2</sub>, (CN)<sub>2</sub>, HCN, cyanogen chloride, bromide and iodide, S chloride, SOCl<sub>2</sub>, NOCl, NO<sub>2</sub>, AsH<sub>3</sub>, SbH<sub>3</sub>, H<sub>2</sub>S and H<sub>2</sub>Se, mercaptans, thiocyanic acid, indole, scatole, aldehydes, chloro-carbonic esters, aromatic chloro and bromo derivatives with the halogen in the side-chain, ethyl bromoacetate and chloro-acetoacetate, chloroacetone, bromoacetophenone, acetic anhydride, etc. The soda-lime acts far more energetically when recently prepared and stored in a hermetically sealed vessel. In view of its distinctive behavior it is probable that it contains a compound such as Ca(ONa)<sub>2</sub>, OH·Ca·ONa, or OH·Ca·O·Ca·ONa. One hundred grams of soda-lime in fine granules will absorb 1,500–2,250 cc. of COCl<sub>2</sub> if the latter is passed slowly through it, but samples prepared from marble exhibit a considerably lower absorptive capacity; when saturated with CO<sub>2</sub>, soda-lime, even when dry, is incapable of arresting COCl<sub>2</sub>. The latter is absorbed well by aniline and other compounds, but soda-lime appears to be the only absorbent of practical value. H<sub>2</sub>S is readily absorbed by soda-lime, which becomes black possibly owing to the formation of Fe sulphide. This reaction is attended with the development of a very considerable amount of heat, and when the current of gas is mixed with air the soda-lime becomes incandescent, while replacement of the air by O results in a violent explosion. This incandescence is observed only with freshly prepared soda-lime, which should consist of granules 1–3 mm. in diameter. One hundred grams of soda-lime absorb as much as 35 l. of H<sub>2</sub>S. Soda-lime also absorbs H<sub>2</sub>Se which produces rapid and intense irritation of the mucous membrane of the nose and is capable of paralyzing the sense of smell for some hours or even days. No investigation has been made on the action of soda-lime on H<sub>2</sub>Te, which is, however only slightly poisonous. SO<sub>2</sub> is absorbed by soda-lime, rapidly at first and subsequently more slowly, 26 l. being taken up by 100 g. NO<sub>2</sub> is absorbed readily, but NO only slowly and to a limited extent. The mixture of HCl, NOCl, NO<sub>2</sub>Cl and Cl obtained from aqua regia is also rapidly absorbed, and the same is the case at first with (CN)<sub>2</sub>, of which more than 6 l. are absorbed per 100 g.; the employment of soda-lime to retain the (CN)<sub>2</sub> emitted from blast furnaces is suggested. Cyanogen chloride, bromide, and iodide are likewise absorbed. Soda-lime rapidly absorbs CO<sub>2</sub> and serves for the removal of the latter from CO, which at the ordinary temperature is absorbed but slightly or not at all. Like all porous substances, soda-lime absorbs a little NH<sub>3</sub>, but forms no compound and allows it to escape; in presence of soda-lime, however, NH<sub>3</sub> causes at the ordinary temperature reactions which otherwise occur only at high temperatures. PH<sub>3</sub> prepared by passing H

into a flask containing 45-40 per cent. KOH solution and a few pieces of P, is spontaneously inflammable, but loses this property when passed through soda-lime; the latter also absorbs P vapor.  $\text{AsH}_3$  and  $\text{SbH}_3$  are absorbed by soda-lime. The latter may, therefore, be used to purify the H obtained by the action of acid on Fe or Zn, but it will not remove  $\text{PH}_3$ , which is detected by the green color of the flame. Soda-lime absorbs many of the impurities of coal-gas and takes away its fetid odor; similar purification and deodorization occur with  $\text{C}_2\text{H}_2$ , which is not absorbed by soda-lime.  $\text{CrO}_2\text{Cl}_2$  is rapidly absorbed, no acid vapor passing.  $\text{SOCl}_2$  is immediately decomposed with development of much heat but no incandescence, no trace being allowed to pass. Ethyl chloroformate is absorbed with avidity, heat being developed; only faint alcoholic-ethereal

odor passes:  $\text{ClCO}_2\text{Et} + \text{Ca} \begin{array}{c} \text{O} \\ | \\ \text{NaOH} \end{array} \rightarrow \text{NaCl} + \text{EtOH} + \text{CaCO}_3$

$\text{CO}_3$ . Chloroacetone is absorbed with generation of heat and replacement of the irritant vapor by one with a pleasant odor:

$\text{CH}_2\text{ClCOMe} + \text{Ca} \begin{array}{c} \text{O} \\ | \\ \text{NaOH} \end{array} \rightarrow \text{OHCH}_2\text{COMe} + \text{NaCl} + \text{CaO}$

$\omega$ -Bromoacetophenone is absorbed. Ethyl bromoacetate is not fixed. Ethyl  $\alpha$ -chloroacetoacetate is readily absorbed. Bromoacetyl bromide is immediately absorbed with liberation of heat. Benzyl bromide and chloride are absorbed. Chlorobenzene is not readily absorbed. Crude xylol or xylolene bromide, probably a mixture of  $\omega$ -bromoxylolene and  $\omega$ ,  $\omega'$ -dibromoxylolene are readily absorbed. Acetaldehyde is readily absorbed. Furfuraldehyde is rapidly absorbed with development of heat.  $\text{CH}_2\text{O}$  is absorbed. Thioformaldehyde is completely and rapidly fixed.  $\text{AcH}$  is absorbed with development of heat. Pyrrole is absorbed but slightly or not at all. Indole and skatole are absorbed.  $\text{S}_2\text{Cl}_2$  is immediately absorbed with heating. Ethyl mercaptan is rapidly absorbed with marked development of heat. Thiophene is fixed either not at all or only in traces.  $\text{HCN}$  is rapidly absorbed with moderate heating.  $\text{SO}_3$  is inefficiently fixed. Acetic anhydride is rapidly absorbed. Various esters undergo hydrolysis. Gases and vapors of putrefaction are absorbed. Products of incomplete combustion of paper, wood, etc., are rendered quite odorless.

For use in warfare, according to Prof. Vivian B. Lewes<sup>1</sup> a gas should have at least twice the specific gravity of air, and should, for ease of transportation, be easily liquefiable. The principal substances which can be used in respirators to absorb the gases more commonly used in warfare are: Carbonate or bicarbonate of soda; sodium hyposulphite; potassium iodide; an alkaline iodide used with an alkaline carbonate; a mixture of alkaline carbonates and thiosulphite; hyposulphite, carbonate and glycerin; carbon. Sodium permanganate protects against arsine, neither soda-lime nor charcoal will.

<sup>1</sup> Engineering July 23, 1915, p. 89.

GAS TOLERANCES AND LETHAL AMOUNTS (PER CENT.)

	Boiling point	Percentage fatal in $\frac{1}{2}$ hr. or less	Percentage dangerous in 0.5-1 hr.	Percentage usually borne for 0.5-1 hr.	Maximum safe concentration
Acrolein.....	52°	0.001	0.25-0.45	0.03	0.00033
Ammonia.....	-35.5°	..	..	0.00004-0.00006	..
Aniline.....	-34.4°	..	..	..	..
Arsine.....	-34.8°	0.05	0.001	0.001-0.0015	0.0005
Benzene.....	80.2°	..	0.004-0.006	0.0004	0.0001
Bromine.....	58.6°	0.1	0.001	0.0002-0.0003	2.0-3.0
Carbon disulphide	45.2°	..	6.0-8.0	4.0-6.0	0.04
Carbon dioxide	-78.2°	30.0	0.2-0.3	0.05-0.10	0.001
Carbon monoxide	-129°	0.5-1.0	0.015-0.02	0.0025-0.004	0.001
Carbon tetrachloride	76.74°	0.03-0.04	0.004-0.006	0.0004	0.0001
Chlorine.....	-33.6°	0.10	0.007	0.0025-0.003	0.001
Chloroform.....	61.2°	0.03-0.04	0.002	0.0001	0.001
Chloropicrin.....	112°	0.05	..	..	0.002
Dichloroethyl sulphide	516°	..	0.15-0.2	0.005-0.01	0.005
Hydrogen chloride..	-82.9°	0.5	0.012-0.024	0.005-0.006	0.002-0.004
Hydrogen cyanide..	26.5°	0.048	0.05-0.07	0.02-0.03	0.01-0.02
Hydrogen sulphide..	-90.2°	0.06-0.1	..	0.0003	0.00005-0.0001
Iodine.....	184.35°	..	..	..	>0.000125
Mercury.....	37.33°	..	..	..	0.002
Mustard gas.....	216°	..	0.01	0.007	0.0033
Nitric oxide.....	-153°	0.07	..	0.0001	0.0002
Nitrobenzene.....	210.9°	..	..	..	0.0001
Phosgene (COCl <sub>2</sub> )..	8.2°	0.02-0.05	0.0025	..	0.0000004
Phosphorus trichloride	76°	0.00035	0.00003-0.00005	0.000002	..
Phosphine.....	-85°	0.2	0.04-0.06	0.01-0.02	0.01-0.02
Sulphureted hydrogen	-60.2°	0.06-0.1	0.05-0.07	0.02-0.03	0.01
Sulphur dioxide.....	-10°	0.2	..	..	0.002
Sulphur trioxide.....	230°	0.001	..	0.00025	0.0001-0.00025
Toluidine.....	..	..	..	..	..

## ANALYSES OF POISON GASES

1. Allyl-iso-thiocyanate (allyl mustard oil)  $C_3H_5NCS$  (shell).
2. Benzyl bromide,  $C_6H_5CH_2Br$  (shell,) tear gas. Bromobenzyl cyanide (shell), tear gas.
3. Bromo-acetone,  $CH_2Br \cdot CO \cdot CH_3$  (hand grenades).
4. Bromated methyl-ethyl-ketone (bromo-ketone),  $CH_2Br \cdot CO \cdot C_2H_5$  or  $CH_3 \cdot CO \cdot CHBr \cdot CH_3$  (shell). Dibromo-ketone,  $CH_2 \cdot CO \cdot CHBr \cdot CH_2Br$  (shell), tear gases.
5. Bromine,  $Br_2$  (hand grenades).
6. Chloro-acetone,  $CH_2Cl \cdot CO \cdot CH_3$  (hand grenades).
7. Chlorine,  $Cl_2$  (cloud).
8. Chloromethyl-chloroformate (palite),  $ClCOOCH_2Cl$  (shell).
9. Nitro-trichloro-methane (chloropicrin or nitrochloroform),  $CCl_3NO_2$  (shell).
10. Chlorosulphonic acid,  $SO_3H \cdot Cl$  (hand grenades and "smoke pots").
11. Dichloro-diethylsulphide (mustard gas),  $(CH_2ClCH_2)_2S$  (shell), causes severe blisters of skin after some hours.
12. Dimethyl sulphate,  $(CH_3)_2SO_4$  (hand grenades), hydrolyzes in lungs to methyl alcoholic sulphuric acid.
13. Diphenyl-chloro-arsine,  $(C_6H_5)_2AsCl$  (shell), sneeze gas.
14. Dichloromethyl ether,  $(CH_2Cl)_2O$  (shell).
15. Methyl-chlorosulphonate,  $CH_3ClSO_3$  (hand grenades).
16. Phenyl-carbylamine chloride,  $C_6H_5NCCl_2$  (shell).
17. Phosgene (carbonyl chloride),  $COCl_2$  (cloud and shell).
18. Sulphur trioxide,  $SO_3$  (hand grenades and shell).
19. Trichloromethyl-chloroformate (diphosgene, superpalite),  $ClCOOCCl_3$  (shell).
20. Xylol bromide (tolyl bromide),  $CH_3C_6H_4CH_2Br$  (shell), tear gas.

**Incendiary Bombs.**—According to Professor Vivian B. Lewes the principal ingredient of incendiary bombs is thermit, ignited by means of amorphous phosphorus. The latter substance is also used by the Germans in a type of shrapnel used for marking the range of artillery. The heat of the explosion converts the amorphous phosphorus into white phosphorus, the combustion of which produces fumes of phosphorus pentoxide, which are visible night and day. Wounds produced by fragments of these shells are poisoned.

## FAILURE OF METALS UNDER REPEATED STRESSES

Materials subjected to repeated stresses fail when a certain limit is exceeded, even when the stresses have never approached the elastic limit. Below this same limit they do not fail, no matter how often the stress be applied. This fact was first brought out by Wohler, and worked on by C. E. STROMEYER of Manchester, England, who called this point the fatigue limit. He gave the following mathematical expression to it. If  $F_l$  be the fatigue limit;  $N$  the number of repetitions of the stress necessary to break the specimen;  $\pm S_n$  the stress applied,

the sign  $\pm$  indicating that  $S_n$  may be applied alternately as a tension or a compression, or an alternate twisting and bending;  $C$  a constant for the material under discussion; then:

$$N = \frac{10^6 C^4}{(S_n - Fl)^4} \text{ or } \pm S_n = Fl + C \sqrt[4]{\frac{10^6}{N}}$$

His tables follow:

Materials	Torsion fatigue		Bending fatigue	
	$Fl$	$C$	$Fl$	$C$
	Tons per sq. in.		Tons per sq. in.	
Chrome nickel steel, F5117.....	12 60 <sup>1</sup>	0.50		
Nineteen samples of chrome nickel steel...	11.37 <sup>1</sup>	0.70		
Manganese steel, F5109.....	11.10 <sup>1</sup>	2.42		
Cast steel.....	10.70 <sup>1</sup>	0.68		
Cast steel.....	7.03 <sup>1</sup>	1.91		
Mild steel plates, high results .....	9 69	1.26	14.08	4 70
Mild steel plates, high results .....	9.71	1.55	13.86	5.46
Mild steel plates, high results .....	11.04	1 11	13 82	5 71
Mild steel plates, high results .....	8.16 <sub>1</sub>	1 55	14 39	4 36
Mean for above mild steels.....	9 05	1.37	14 04	5 06
Mild steels, exceptional qualities.....	7.56	2 40	13.30	5.40
Mild steels, exceptional qualities.....	8.64	1.26	doubtful	
Mild steel plates, low results .....	7.01	1.36	9 36	5 31
Mild steel plates, low results .....	7.09	1.26	8 94	4.76
Mild steel plates, low results .....	6.33	2.03	8 95	5.13
Mild steel plates, low results .....	6.94	1.69	8 15	5.61
Mild steel plates, low results .....	5.54	1.43	9 69	4.53
Mild steel plates, low results .....	5 90	1.58	7.42	5.17
Mean .....	6 47	1.56	8 75	5.09
Mild steel rods.....	6.83 <sup>1</sup>	1 60		
Mild steel rods.....	5.97 <sup>1</sup>	0.97		
Pure nickel rods.....	6 22 <sup>1</sup>	1.83		
Farnley iron rods.....	6.00 <sup>1</sup>	0.61		
Copper rods as rolled.....	5 50 <sup>1</sup>	0.41		
Copper rods annealed.....	2 69 <sup>1</sup>	0.97		
Aluminum rods as rolled.....	2 16 <sup>1</sup>	0 13		
Cast iron (one sample).....	3 98	1.61		
Phosphor bronze rods, as rolled ..	7.82 <sup>1</sup>	0 77		
Magnesium rods, as rolled .....	4.21 <sup>1</sup>	0 78		
Duralium rods, as rolled .....	5.80 <sup>1</sup>	negative		
Monel metal.....	15.0			

<sup>1</sup> These fatigue limits were determined calorimetrically.

Since that time (1914), W. H. MOORE of the University of Illinois, has greatly extended the work, and introduced the term "endurance limit" instead of "fatigue limit." The U. S. Naval Laboratory has also done a great deal of research on the subject, and some of their experimental results are given in accompanying tables.

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## STATIC TESTS AND FATIGUE TESTS ON METALS AT ELEVATED TEMPERATURES

Static tension tests						Fatigue tests	
Temperature, deg. F.	Proportional elastic limit <sup>1</sup>	Ultimate tensile strength		Elonga- tion in 2 in.	Reduction of area, percent.	Temperature, deg. F.	Endurance limit (rotating- beam test 1500 r.p.m.), reversed flexure test, lb. per sq. in.
		Ordinary test	Prolonged and retarded test	Ordinary test, per cent.			
	Lb. per sq. in.						

### No. 2. Cyclops metal, annealed

70	45 200	112 500			52	70	56 000
400	45 600	102 600	101 000	21.0	48	500	52 000
600	42 800	99 900	99 600	20.2	43	875	46 000
800	41 400	97 100	97 700	19.5	38	1200	35 000
1000	39 000	85 500	82 000	19.8	44	1300	{ less than 30 000
1200	35 800	74 600	51 900	19.3	48		
1250	26 200	65 400	46 300	18.5	49		

### No. 10 0.49 Carbon steel, normalized

70	44 700	91 500		26.5	40	70	36 000
330	42 800	93 500		13.3	40	550	39 000
400	42 000	97 000		12.0	32	800	44 000
600	37 500	128 000	110 700	13.5	20	1150	24 000
800	31 200	84 900	78 800	24.0	60		
875	26 400		59 000	26.0	72		
1000	23 600	59 700	35 200	19.0	72		
1100	17 100	57 300	24 200	27.0	78		
1230	8 200	31 000	16 400	28.3	84		

### No. 11 1.02 Carbon steel, treatment "A"

70	109 000	200 400		9.3	22	70	105 000
400	105 000	180 000	188 000	8.3	47	585	86 000
600	88 500	178 500	144 000	9.8	58	800	80 000
700	72 000	167 300	98 000	16.0	69	900	75 000
800	74 500	154 100	89 000	13.0	72	1050	62 000
	60 000	101 000	82 400	17.0	78	1200	{ less than 30 000
1000	44 500	81 000	53 700	17.3	77		
1100	32 300	69 500	39 700	21.4	78		
1200	12 600	31 400	24 200	27.6	78		
1250	6 000	20 100	10 000	29.5	80		

<sup>1</sup> Average of results from ordinary tests and prolonged and retarded tests.



# PHYSICAL CONSTANTS

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No. 13. S. A. E. Steel 2340, treatment "C"<sup>1</sup>

70	136 300	164 900		10.8	58	70	76 000
400	119 000	183 700		9 0	57	460	82 000
600	108 500	157 100	148 500	10.0	50	650	69 000
						875	68 000
800	81 300	163 500	97 200	14.8	76	1150	{ less than
900	68 800	117 000	88 100	17.2	82		30 000
1000	39 800	99 200	60 100	20.8	81		
1100	19 300	52 900	26 800	21.3	88		
1230	7 800	17 900	14 100	37.5	93		

No. 13 S. A. E. Steel 2340, treatment "E"<sup>1</sup>

70	103 700	125 100		14.8	63	70	74 000
400	85 500	110 500	119 000	11.8	57	460	75 000
600	84 000	113 900	121 000	14.5	44	650	65 000
						875	62 000
800	71 000	113 000	93 400	18 0	64	1000	55 000
900	56 000	92 200	70 300	20 5	75		
1000	42 200	80 700	45 600	21 2	79		
1100	23 700	52 500	32 200	24.0	86		
1200	8 300	37 400	17 600	26.8	89		
1250	4 500	25 400	13 900	30.8	91		

No. 106. Nickel, annealed

70	11 300	68 700		45 1	72		
400	14 500	69 100	69 100	35 5	75		
600	14 200	68 900	76 500	35 0	72		
800	12 900	67 800	59 500	41 0	72		
1000	11 700	47 400	40 100	43 0	78		
1100	9 800	43 900	28 400	48 0	78		
1200	8 300	38 400	21 000	42 5	76		

No. 111 Monel metal, hot-rolled

70	49 600	80 800		40.4	69		
400	50 000	83 500	79 500	21 5	71		
600	49 500	80 400	81 200	17 5	69		
800	49 500	77 100	77 200	18 0	61		
1000	44 300	69 500	53 300	20 0	56		
1100	40 000	62 700	49 000	20 5	47		
1200	31 200	53 600	38 100	17 0	36		
1250	29 000	49 600	35 600	16 5	38		

<sup>1</sup> S. A. E. 2340 steel treatment C: Heat to 1525°F.; hold 30 min.; cool in furnace; reheat to 1450°F.; hold 15 min.; quench in oil; reheat to 800°F.; hold 30 min.; cool in air. Treatment E: Heat to 1525°F.; hold 80 min.; cool in furnace; reheat to 1450°F.; hold 15 min.; quench in oil; reheat to 1200°F.; hold 30 min.; cool in air.

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## TENSION TESTS AND FATIGUE TESTS OF NON-FERROUS METALS<sup>1</sup>

Designation	Results of tension tests				Endurance limit (rotating-beam), lb. per sq. in.
	Proportional elastic limit	Ultimate tensile strength	Elongation in 2 in.	Reduction of area	
	Lb. per sq. in.		Per cent.		
Tests at U. S. Navy Engineering Experiment Station (Annapolis)					
Nickel, hot-rolled.....	20 700	60 100	53 0	74	25 500
Nickel, annealed.....	30 000	76 200	47.0	69	31 000
Aluminum bronze.....	..	71 900	42 9	66	19 000
Monel, cold-rolled finish No. 13..	..	88 300	28.9	57	29 000
Monel, cold-rolled finish No. 9.....	..	97 400	28 5	72	33 000
Monel, hot-rolled..	56 200	90 200	35 9	70	38 000
Test at U. S. Air Service Laboratories (McCook Field, Dayton)					
Aluminum.....	11 300	22 600	16 0	65	10 500
Magnesium.....	11 200	32 500	6.2	4	8 000
Naval brass.....	33 400	68 200	27.0	53	22 000
Electron metal.....	6 300	36 500	17.5	20	17 000
Aluminum bronze, as cast.....	5 100	59 300	20.0	28	23 000
Aluminum bronze, cast, heat treated ..	24 900	77 800	14.0	19	27 000
Manganese bronze, cast.....	13 000	70 000	32.8	41	17 000
Mg + 4% Al.....	8 100	35 200	21.7	28	12 000
Mg + 4% Al + 1/4% Mn.....	13 500	39 000	15.5	31	15 000
Mg + 6.5% Al ..	12 000	41 300	16.0	20	13 000
Mg + 6.5% Al + 1/4% Mn.....	15 000	44 400	13 8	17	15 000
Mg + 10% Cu.....	14 200	39 000	3 0	4	12 000
Duralumin, as rec'd.....	25 000	51 000	16.0	50	14 000
Duralumin, annealed..	6 800	25 200	25.0	61	10 000
Duralumin, heat treated.....	18 600	51 200	29.3	48	12 000
Electron metal.....	6.260	16.970	17 5	20.5	17 000
Manganese bronze.....	13 000	43.190	32 8	40.8	15 000
Tests at University of Illinois					
Copper, annealed.....	3 200	32 400	56 4	72	10 000
Copper, cold drawn.....	38 400	56 200	6.5	52	10 000
Brass, annealed.....	23 600	66 000	48 1	40	29 000
Bronze, annealed.....	12 800	45 700	66 9	84	28 000
Bronze, cold drawn.....	59 900	85 100	11.7	67	27 000
Brass, annealed.....	15 600	54 200	56.0	61	22 000
Brass, cold drawn.....	43 200	96 700	12.8	52	26 000
Nickel, annealed.....	11 300	69 900	45.1	72	28 000
Monel, hot rolled, as rec'd (G. E.).....	49 600	89 800	40.4	69	32 000
Monel, as rec'd (A.C.).....	50 700	89 600	35.6	68	32 000

<sup>1</sup> Courtesy of The Engineering Foundation, Bull., "Investigation of the Fatigue of Metals."

The tables give valuable data as to the strengths of materials at high temperatures. Metals which at ordinary room temperatures are crystalline and, within certain limits, elastic, begin to exhibit, at high temperatures, some of the properties of plastic, amorphous materials. The values given under "Tensile strength, prolonged and retarded test," pp. 226-228, show these plastic properties, and give distinct warning that we must use much higher factors of safety at high temperatures if we are using ordinary ultimate tensile strength tests.

That the stresses are alternately plus and minus, and reverse the creep due to plasticity, is doubtless the reason that the fatigue limit at high temperatures often exceeds the ultimate tensile under prolonged and retarded test.

In reference to general points in connection with the subject, it may be noted cold drawing and rolling increase the fatigue limit of most non-ferrous metals, just as they do the proportional elastic limit and the ultimate tensile strength. The ratio of fatigue limit to ultimate tensile ("endurance ratio") is not changed. Repeated stressing below the fatigue limit is equivalent to cold working. The general effect of cold-working in raising the fatigue limit and ultimate tensile gives a scientific reason for running engines, automobiles, etc. lightly for the first part of their lives.

For most wrought ferrous metals it was found that by measuring the rise of temperature under reversed flexure, and plotting rise of temperature against unit stresses, the "break" of the resulting diagram locates the endurance limit fairly well. For non-ferrous metals this "rise-of-temperature" method is not accurate.

Cracks, nicks and grooves, shoulders with short-radius fillets and poor surface finish, greatly lower the fatigue limit. Stresses above the fatigue limit, when not themselves applied often enough to destroy the member, appear to reduce the limit.

Corrosion also greatly reduces the fatigue limit both because of actual pitting and because of occluded hydrogen.

**Drawing Zinc.**—Due to the low annealing temperature of high-grade zinc, which makes it practically self-annealing at room temperature, it is unnecessary to anneal products drawn from this grade of strip between successive drawing operations. It has been found desirable to maintain the stock and dies for these operations at a fairly warm room temperature, 80° to 85°F. A serious drop in ductility may be encountered if the metal is drawn or formed at temperatures below 60°F. Actual annealing of the stiffer cold-worked grades of rolled zinc occurs at temperatures in the neighborhood of 212°F. and usually results in a grain coarsening with corresponding detrimental changes in important physical properties.

In the deep drawing of zinc the metal is formed during the successive steps into the desired shape without a reduction in the thickness of the stock at any time. The following direc-

<sup>1</sup> C. S. TREWIN, *Trans. A.I.M.E.*, 1927.

tions have been found useful in determining the design of successive drawing operations:

1. Compute the total area of the finished cup and add to this sufficient area to allow a trim of  $\frac{1}{4}$  in. on the finished cup.

2. Calculate the diameter of the circle of a blank having the above area.

3. The reduction in diameter<sup>1</sup> from the blank to the first cup should not exceed 40 per cent. of the diameter of the blank.

4. The reduction in diameter<sup>1</sup> of succeeding cups should not exceed 20 per cent. of the preceding cup.

5. Die clearances should be twice the thickness of the stock plus 0.001 or 0.0015 in. Filets should be generous.

6. Soapy water is a very satisfactory lubricant.

When machining is necessary, particularly with the purer grades of zinc, an excessively long chip is encountered. This has been successfully overcome by the use of tools with a greater rake than is normally used.

**Single crystals of metal may be prepared** (a) by annealing at a rather high temperature to promote grain growth; often a slight straining before the annealing facilitates this growth; (b) by drawing polycrystalline wires at a determined speed through a sharp temperature gradient, as in the preparation of single crystals of tungsten; (c) by starting solidification of a metal in a capillary tube and gradually increasing the size of the tube; (d) by drawing the molten metal through a sharp temperature gradient which freezes the metal quickly. This is produced by a stream of non-corrosive gas directed against the metal. The speed of the drawing must be practically constant. (ORLANDO E. ROMIG, *Trans. A. I. M. E.*, 1927.)

**Effect of Cold-working on Hardness.**—The belief is general that cold-rolling increases the hardness of the metal rolled. According to H. S. RAWDON and W. H. MUTCHLER (*Trans. A. I. M. E.*, February meeting, 1924) this effect is produced only in the early stages of rolling, then a maximum hardness is reached and a reversal occurs, the specimen becoming softer as the cold working is continued. If cracking or splitting occurs, it will take place during the stages of deformation represented by the descending branch of the curve, and usually near the minimum, that is, at the time of greatest hardness.

**General Rules for Test Specimens.**—When possible test specimens for forgings shall be taken from full-size prolongations which have received the same mechanical and heat treatments

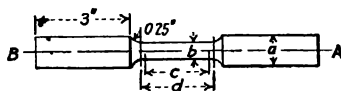


FIG. 1.

as the forgings. Test specimens from castings shall be taken from coupons attached to the casting, if possible, otherwise test-specimens shall be cast separately. Test-specimens must

<sup>1</sup> A flange must be included in the diameter.

not be hammered, annealed or heat treated unless the same treatment is given the metal that they represent.

The faces of the test specimens must be plane and parallel.

The base of the notch must be of uniform depth and perpendicular to the longest axis of the specimen.

The notch shall be drilled and slotted in test specimens which have not been heat treated.

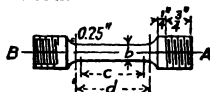


FIG. 2.

In heat-treated test specimens, the notch may be milled or ground.

Test specimens prepared as shown in Fig. 4 shall be used for sheet  $\frac{1}{8}$  in. (5.08 mm.) (No. 6 U. S. standard gage) and more in thickness. For sheets less than  $\frac{1}{8}$  in. (5.08 mm.) in thickness,  $W$  and  $d$  shall be  $\frac{1}{2}$  in. (12.70 mm.);  $h$  shall be  $1\frac{1}{2}$  in. (38.10 mm.), and  $W_h$  shall be 1 in. (25.40 mm.). The per-

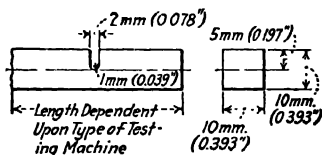


FIG. 3.

centage of elongation may be determined on either 2 or 4 in. (50.80 or 101.60 mm.). Soft materials of light gage may be gripped in the jaws of the testing machine, in which case drilling shall be omitted.

The specimens may be reduced in width by not more than 0.003 in. (0.08 mm.) over the center half of the gage length. Specimens must be the full thickness of the material.

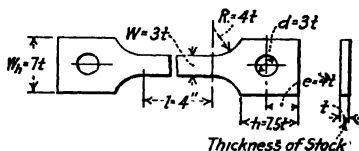


FIG. 4.

The distance 'X' shall conform to the values called for in individual specifications.

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## DIMENSIONS OF TENSILE TEST SPECIMENS

Diameter of bars	Cross-section over gage length	Dimensions			
		a	b Di- ameter over gage length	c Gage length	d
	Square inches	Inches	Inches	Inches	Inches
Over $\frac{5}{16}$ in.....	0.20	Not over 1	0.505	2.00	2.25
$\frac{1}{4}$ to $\frac{5}{16}$ in.....	0.10	Not over 1	0.358	1.42	1.75
$\frac{3}{16}$ to $\frac{1}{4}$ in.....	0.05	Not over 1	0.252	1.01	1.25
$\frac{1}{8}$ to $\frac{3}{16}$ in.....	0.02	Not over 1	0.159	.64	1.00
	Square millimeters	Millimeters	Millimeters	Millimeters	Millimeters
Over 15.88 mm.....	129.0	Not over 25.4	12.83	50.80	57.15
12.70 to 15.88 mm....	64.5	Not over 25.4	9.09	36.07	44.45
9.53 to 12.70 mm....	32.3	Not over 25.4	6.40	25.65	31.75
6.35 to 9.53 mm....	12.9	Not over 25.4	4.04	16.26	25.40

Test specimens may be tapered inside the gage length (c) toward the center to an amount not to exceed 0.003 in (0.08 mm.). The diameter at the center (b) shall conform to the dimensions specified in the above table.

The ends of test specimens may be either threaded or unthreaded (Fig. 1) or prepared as shown in Fig. 4.

**Bend Test for Sheets.**—This test comprises two distinct operations: first, the test strip is placed in the testing machine in position *AB* (Fig. 5a) on a block having a V-shaped groove.

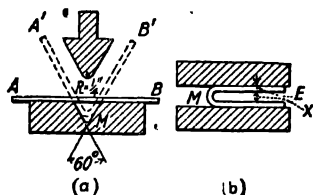


FIG.

The knife edge is placed as shown and pressure is applied until the test specimen assumes the shape *A'MB'*. The block is then removed and the bending completed as indicated in Fig. 5b with or without the interposition of a spacer. The specimen must stand this test without breaking and must not show hair lines, cracks, or other defects.

## Some Properties of the Metals -

**Brittleness or Toughness (MARTEN'S Formulæ).—**Toughness of test length =

$$\frac{\text{ultimate strength}}{\text{yield point}} \times \frac{\text{per cent. elongation in test length.}}{100}$$

The metals then range in this order:

Pb, Pt, Fe, Al, Ni, Zn, Sn, Cu, Au, Ag.

**Ductility.**—W, Au, Ag, Pt, Fe, Ni, Cu, Al, Zn, Sn, Sb.

By some authorities aluminum is placed fourth; it has been drawn so fine that 11,400 yd. weigh only 1 oz. One ounce of tungsten at 0.0005 inch diam. equals 12,490 yd. (FINK).

**Tenacity.**—Steel, Ni, Fe, Cu, Al, Au, Zn, Sn, Pb.

**Malleability.**—Au, Ag, Al, Cu, Sn, Pt, Pb, Zn, Fe, Ni.

The thinnest metal leaf commercially attainable in 1914 was: Au, 0.000008 cm.; Al, 0.000020; Ag, 0.000021; Pt, 0.000025; Cu, 0.000034; Dutch metal, 0.00007 (KAYE and LABY). Electrolytic zinc (by the Tainton process) is said to have been beaten into sheets 0.000063 in. thick.

**Plasticity (MARTEN'S Formulæ).—**Plasticity =  $\frac{\text{toughness}}{\text{yield point}} \times 1000$ .

**MARTEN'S Classification.**—Fe, Pt, Ni, Al, Zn, Cu, Ag, Au, Pb, Sn.

**KURNAKOFF-SCHEMTSCHUSCHNY:** K, Na, Pb, Tl, Sn, Bi, Cd, Zn, Sb.

**Bulk Modulus.**—If the volume of a body be altered without changing its shape, the stress divided by the strain is known as the bulk modulus:  $k = \frac{vp}{\Delta v}$ .

**Coefficient of Rigidity, Modulus of Elasticity.**—If a body be changed in shape without changing its volume the modulus of elasticity is the ratio of the stress to the strain which produces it. If  $P = kg$  of stress applied,  $K =$  the sectional area,  $l$  the length measured and  $\lambda$  the elongation in that length, then the modulus of elasticity  $E = \frac{P}{K} \div \frac{\lambda}{l} = \frac{Pl}{K\lambda}$ .

**YOUNG'S Modulus.**—The number representing the pressure or tension on a bar in dynes per square centimeter divided by the compression or elongation so produced per centimeter of length.

**Proportional Limit.**—Stress at which the deformation (or deflection) ceases to be proportional to the load (the value is read from plotted tests).

**Elastic Limit.**—In tensile and compressive tests, the stress at which the initial permanent elongation, or shortening, of the gage length occurs. For practical purposes this may be regarded as equal to the proportional limit.

**Yield Point.**—Stress at which marked increase in deformation occurs without increase in load.

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ELASTIC CONSTANTS OF SOLIDS  
(Pounds per Square Inch)

	Bulk modulus	Coefficient of rigidity	Young's modulus
Aluminum. . . . .	$10.8 \times 10^6$	$3.82 \times 10^6$	$10.2 \times 10^6$
Bismuth, cast. . . . .	$4.55 \times 10^6$	$1.74 \times 10^6$	$4.63 \times 10^6$
Brass. . . . .	$14.5 \times 10^6$	$5.36 \times 10^6$	$15.1 \times 10^6$
Bronze. . . . .	$9.52 \times 10^6$	$4.30 \times 10^6$	$8.08 \times 10^6$
Cadmium. . . . .	$5.98 \times 10^6$	$2.78 \times 10^6$	$7.24 \times 10^6$
Constantan. . . . .	$22.2 \times 10^6$	$8.86 \times 10^6$	$23.6 \times 10^6$
Copper. . . . .	$19.0 \times 10^6$	$6.60 \times 10^6$	$17.8 \times 10^6$
Duralumin. . . . .		$3.84 \times 10^6$	$10.1 \times 10^6$
Electron metal. . . . .		$2.16 \times 10^6$	$6.13 \times 10^6$
German silver. . . . .		$6.53 \times 10^6$	$16.8 \times 10^6$
Glass. . . . .	$5.8 \times 10^6$	$3.48 \times 10^6$	$8.7 \times 10^6$
Gold. . . . .	$24.1 \times 10^6$	$4.06 \times 10^6$	$11.6 \times 10^6$
Iron (cast). . . . .		$12.0 \times 10^6$	$15.0 \times 10^6$
Iron (wrought). . . . .	$21.2 \times 10^6$	$11.2 \times 10^6$	$28.5 \times 10^6$
Lead. . . . .	$7.25 \times 10^6$	$0.83 \times 10^6$	$0.70 \times 10^6$
Lead (hard). . . . .			$2.35 \times 10^6$
Magnesium. . . . .	$6.1 \times 10^6$	$2.46 \times 10^6$	
Manganese bronze. . . . .		$4.6 \times 10^6$	$14.2 \times 10^6$
Manganin. . . . .	$17.5 \times 10^6$	$6.75 \times 10^6$	$18.0 \times 10^6$
Monel metal. . . . .		$9.0 \times 10^6$	$25.0 \times 10^6$
Nickel. . . . .	$25.6 \times 10^6$	$11.2 \times 10^6$	$29.3 \times 10^6$
Palladium. . . . .	$25.6 \times 10^6$	$5.85 \times 10^6$	$16.4 \times 10^6$
Phosphor bronze. . . . .	$17.4 \times 10^6$	$6.32 \times 10^6$	$17.4 \times 10^6$
Platinum. . . . .	$35.8 \times 10^6$	$8.75 \times 10^6$	$24.4 \times 10^6$
Quartz. . . . .		$0.19 \times 10^6$	$9.4 \times 10^6$
Rhodium. . . . .	$40.5 \times 10^6$		
Silver. . . . .	$15.8 \times 10^6$	$4.15 \times 10^6$	$11.5 \times 10^6$
Steel. . . . .	$26.7 \times 10^6$	$28.0 \times 10^6$	$31.9 \times 10^6$
Tantalum. . . . .	$27.0 \times 10^6$		$13.2 \times 10^6$
Tin. . . . .	$7.66 \times 10^6$	$2.94 \times 10^6$	$7.87 \times 10^6$
Tungsten. . . . .			$61.2 \times 10^6$
Wood oak. . . . .		$0.97 - 2.28 \times 10^6$	
walnut. . . . .		$0.31 \times 10^6$	
Zinc. . . . .	$13.05 \times 10^6$	$5.5 \times 10^6$	$12.6 \times 10^6$

COMPRESSIBILITY OF METALS  
(Per Kg per Square Centimeter)

Cu. . . . .	$0.76 \times 10^{-6}$
Fe. . . . .	$0.61 \times 10^{-6}$
Ga (liquid) . . . . .	$3.97 \times 10^{-6}$
(solid). . . . .	$2.09 \times 10^{-6}$
Hg. . . . .	$3.96 \times 10^{-6}$
Mg. . . . .	$2.9 \times 10^{-6}$
Mo. . . . .	$0.47 \times 10^{-6}$
Ta. . . . .	$0.54 \times 10^{-6}$
W. . . . .	$0.28 \times 10^{-6}$



**STRENGTH OF MATERIALS AT ORDINARY TEMPERATURES**  
(Pounds per Square Inch)

	Proportional limit	Ultimate tensile	Brinnell, 500 kg.
Aluminum, cast. . . . .	8,500 to 10,000	12,000 to 14,000	25-26
Aluminum, hard sheet. . .	20,000	30,000	
Aluminum, hard bars . . .	22,000	33,000	
Aluminum, wire. . . . .	30,000	40,000	
Antimony, cast . . . . .		1,000	
Beryllium (electro.). . . .			140
Bismuth, cast . . . . .		3,000	
Brass, 90 Cu, cast . . . . .		29,000	
Hard rolled . . . . .		55,000	60
Brass, 80 Cu, cast. . . . .		35,000	
Hard rolled . . . . .		75,000	75
Brass, 70 Cu, cast. . . . .		40,000	37
Bronze, 90 Cu . . . . .	10,300	33,000	
80 Cu. . . . .	10,100	32,000	
70 Cu. . . . .	2,000	7,000	
Calcium . . . . .		10,240	42 5
Cobalt, cast. . . . .	27,800	32,900	121
Copper, electro, cast . . .		24,000	
Casting, cast. . . . .	10,000	25,000	80
Hard drawn . . . . .		60,000	
Soft drawn. . . . .		31,200	
German silver . . . . .		66,000	
Gold, cast, 24 k. . . . .		25,000	
Hard drawn. . . . .		37,000	
Annealed . . . . .		24,000	
90 Au, 10 Cu. . . . .		65,100	73
Hard rubber . . . . .		7,000	
Iron, electrolytic . . . . .	48,500	55,000	95
Gray cast . . . . .		25,000 to 38,000	100 to 150
Malleable. . . . .	20,000 to 45,000	35,000 to 57,000	
Wrought . . . . .	28,000 to 32,000	48,000 to 50,000	100 to 145
Lead, antimonial . . . . .	4,000	6,000	17 5
Desilverized, cast . . .		1,780	
Desilv, rolled. . . . .		2,400 to 3,100	
Magnesium. . . . .		30,000	
Molybdenum . . . . .		260,000 <sup>1</sup>	147
Nickel (99.95%) . . . . .	17,900	45,000	
(98 5%) cast. . . . .	23,800	38,000	
Hard rolled . . . . .		92,000	350
Hard drawn. . . . .		155,000 <sup>1</sup>	
Palladium . . . . .		39,000	
Platinum, cast . . . . .		45,000	35
Hard drawn. . . . .		53,000	90
Quartz, annealed . . . . .		32,000	
Fused. . . . .		7,000	
Silver (1,000 fine) . . . . .		40,000	
75 Ag, 25 Cu . . . . .		109,500	
Steel, high tensile . . . . .		450,000 <sup>1</sup>	
0.05 to 0.15C . . . . .	40,000 to 60,000 (a)		
0.15 to 0.25C. . . . .	40,000 to 75,000 (a)		
0.20 to 0.30C . . . . .	41,000 to 80,000 (b)	75,000 to 90,000 (b)	
0.30 to 0.40C . . . . .	50,000 to 75,000 (b)	82,000 to 105,000 (b)	
0.40 to 0.50C . . . . .	60,000 to 90,000 (b)	95,000 to 125,000 (b)	
Cast, hard . . . . .	36,000	80,000	
Cast, soft . . . . .	27,000	60,000	
Tantalum . . . . .		130,000	45.9
Tellurium. . . . .		8,500	
Tungsten. . . . .		215,000	290
Tin, cast . . . . .	1,600	4,000	
Hard drawn. . . . .		10,000	
Zinc, cast. . . . .		4,000 to 12,000 <sup>2</sup>	42 to 48
Rolled. . . . .	5,800	36,000	

(a) Cold rolled.

(b) Hot drawn.

<sup>1</sup> Small wire—0.065 in. or less

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### TENSILE STRENGTH OF BOILER PLATE AT ELEVATED TEMPERATURES

Temp. deg. F.	Proport limit, lb. per sq. in.	Max. tensile, lb. per sq. in.	Per cent. elongation	Per cent. reduction of area
---------------	-----------------------------------	----------------------------------	-------------------------	-----------------------------------

½ in. Firebox Plate: C, 0.19; Mn, 0.43; P, 0.020; S, 0.031 per cent.

70	23,300	59,000	37.75	57.1
196	23,630	55,530	34.7	58.3
313	26,600	58,100	24.9	49.3
469	24,900	65,130	19.8	45.1
563	15,250	66,700	25.7	45.6
765	12,960	49,150	33.75	60.7
871	11,430	41,850	39.2	67.7

½ in. Marine Boiler plate: C, 0.25, Mn, 0.38; P, 0.19; S, 0.31 per cent.

70	31,200	66,700	38.3	64.0
199	31,766	63,166	35.25	63.9
313	31,450	67,200	26.65	58.4
466	27,233	71,633	19.6	45.5
559	22,450	72,500	21.25	48.2
759	15,933	62,833	33.75	67.1
869	12,500	55,566	35.25	70.7

Each value is average of three determinations

### TENSILE STRENGTHS AT HIGH TEMPERATURES

(Pounds per Sq. In., Slow Loading)

	400°	600°	800°	900°
Aluminum . . . . .	16,000	3,000	.....	.....
Molybdenum . . . . .	100,000	96,000	.....	.....
Monel Metal . . . . .	79,500	81,200	77,100	47,300
Nickel . . . . .	107,000	83,000	13,000	8,500

TENSILE STRENGTHS AT LOW TEMPERATURES<sup>1</sup>

	In kg. per sq. cm.		
	At -252.6°C.	-192°C.	+17°C.
Aluminum.....	4,790	5,370	2,900
Copper.....	6,510	4,880	3,580
Gold.....	.....	13,400	9,860
Iron.....	21,700	19,700	14,700
Lead.....	813	581	251
Nickel.....	11,000	10,900	9,350
Platinum.....	8,600	7,250	5,080
Silver.....	6,400	5,390	2,780

H. O. HOFMAN, "General Metallurgy"

<sup>1</sup> F. A. and C. L. LINDEMANN, *Nernst's Festschrift*, 1912, p. 264.TENSILE STRENGTH OF METALS, SHOWING EFFECT OF DRAWING AND ROLLING<sup>1</sup>

	Lb. per sq. in.		
	Cast	Thin sheet metal	Wire
German silver.....	23,714-46,450	75,816-87,129	81,735-92,224
Bronze.....	35,960	73,380-92,086	78,049
Brass.....	.....	44,398-58,188	81,114-98,578
Copper.....	24,781	30,470-48,450	37,607-62,190
Iron (lengthwise).....	.....	44,331-59,484	59,246-97,908
Iron (crosswise).....	.....	39,838-57,350	.....
Steel (lengthwise).....	.....	49,253-78,251	103,272-318,823
Tungsten.....	.....	100,000-610,000	.....

<sup>1</sup> Rearranged from tests quoted in KENT'S "Mechanical Engineers' Pocket Book."COEFFICIENTS OF LINEAR EXPANSION PER DEGREE CENTIGRADE<sup>1</sup>

	0°-100°	-190°-0°
Aluminum.....	0.0000233	0.000183
Antimony.....	0.0000168	.....
Antimony (normal to axis).....	0.0000089	.....
Arsenic.....	0.000017	.....
Bismuth.....	0.0000157	0.000013
Brass.....	0.000019	.....
Brick.....	0.0000055	.....
Bronze.....	0.0000185	.....
Cadmium.....	0.000031	0.0000446
Cement.....	0.0000143	.....
Cobalt.....	0.0000123	.....
Copper.....	0.0000179	0.0000141
Gas-carbon.....	0.0000054	.....
Glass.....	0.0000035	.....
Gold.....	0.0000145	0.0000132

<sup>1</sup> The coefficient of cubic expansion is 3 times the coefficient of linear expansion.

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## COEFFICIENT OF LINEAR EXPANSION PER DEGREE CENTIGRADE

	0°-100°	-190°-0°
Glucinum...	12.0	7.0
Graphite (artificial)...	0.0000025	
Indium...	0.0000459	
Invar (63.8 per cent. Fe, 36.2 per cent. Ni)	0.00000044	
Iridium...	0.0000067	0.0000057
Iron (cast)...	0.0000122	0.0000091
Iron (wrought).....	0.0000119	
Lead.....	0.0000295	0.0000271
Magnesium.....	0.0000276	0.0000214
Marble.....	0.000007	
Mercury (solid).....	0.000181	
Molybdenum.....	0.000005151	
Monel metal.....	0.000014	
Nickel.....	0.0000132	0.0000101
Osmium.....	0.0000068	
Palladium.....	0.0000119	0.0000120
Platinum.....	0.0000088	0.0000088
Potassium.....	0.000083	
Rhodium.....	0.0000086	
Ruthenium.....	0.0000099	
Selenium (40°).....	0.000037	
Silver.....	0.0000195	
Sodium.....	0.000072	
Steel.....	0.000011	
Steel (hardened).....	0.0000136	
Tantalum.....	0.0000079	
Tungsten.....	0.0000044	
Tellurium.....	0.000017	
Thallium.....	0.000031	
Tin.....	0.0000227	0.0000226
Zinc.....	0.0000354	0.0000295
Aluminum bronze.....	0.000017	
Brass (Cu 66, Zn 34).....	0.0000189	
Bronze (Cu 32, Zn 2, Sn 5).....	0.0000177	
Constantan (Cu 60, Ni 40).....	0.000017	
German silver (Cu 60, Ni 15, Zn 25).....	0.0000184	
Magnalium (Al 86, Mg 13).....	0.000024	
Phosphor bronze (Cu 97.6, 2Sn, P 0.2).....	0.0000168	
Platinum-iridium (Ir 10 per cent).....	0.0000087	
Solder (Pb 2, Sn 1).....	0.000025	
Speculum metal (Cu 68, Sn 32).....	0.0000193	
Cement and concrete.....	0.000010-14	
Glass, soft 68SiO <sub>2</sub> , 14Na <sub>2</sub> O, 7CaO.....	0.0000085	
Glass, flint 45SiO <sub>2</sub> , 8K <sub>2</sub> O, 46PbO.....	0.0000078	
Granite.....	0.0000083	
Ice (-10° to 0°).....	0.0000507	
Masonry.....	0.000004-7	
Rubber, hard.....	0.00004278	
Silica, fused (-80° to 0°).....	0.0000022	
(0° to 30°).....	0.00000042	
(0° to 1000°).....	0.00000054	
Sandstone.....	0.000007-12	
Slate.....	0.000006-10	

CUBIC EXPANSION OF GASES, PER DEGREE CENTIGRADE<sup>1</sup>

	Constant volume	Constant pressure
Air.....	0.0036650	0.003676
Carbon monoxide.....	0.0036667	0.0036688
Carbon dioxide.....	0.003688	0.00371
Cyanogen.....	0.003829	0.003877
Hydrogen.....	0.0036678	0.0036613
Nitrogen.....	0.0036682	0.003670
Oxygen.....	0.0036741	0.00486
Nitrous oxide.....	0.003676	0.0037195
Ammonia.....	.....	0.003854
Sulphur dioxide.....	0.0038453	0.0039028
Argon.....	0.003668	.....
Helium.....	0.0036627	.....

<sup>1</sup> From "Annuaire pour 1914, Bureau des Longitudes," with a few values from other sources.

## CUBIC EXPANSION OF LIQUIDS

Mercury (0° — 100°C.) .....	0.0001818
Water .....	see p. 174
Burning oils of sp. gr. 0.795–0.825....	0.00072
Benzine .....	0.00081
Light lubricating oil ..	0.00068
Heavy lubricating oil.....	0.00063
Sodium (liquid) ..	0.000226

## Hardness

"The customary hardness test at the present time is that of BRINELL, which consists in making on a flat surface of the material an indentation by means of a small steel ball applied under known pressure. According to ROSENHAIN perhaps the best definition of hardness is "the power of resisting local displacement of portions of its surface." But it is at once evident that this power is by no means a simple and definite property of the material which will reproduce itself in all circumstances. Thus the displacement of a portion of the substance of a material may occur by plastic flow—the material may be indented at one point while its level is raised at other points; in other circumstances or in other materials the displacement may occur by direct fracture, as in the scratching of a brittle material. Either of these forms of local displacement may be brought about by the application of a steadily increasing force or by a rapidly applied force, i.e., by a shock or blow. It is by no means certain that the power of resisting all these various forms of displacement will be identical or even proportional, so that the material which displays the highest scratch hardness is not

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necessarily the hardest under an indentation test. Where hardness is referred to, therefore, the manner of measuring it should always be specified.

SCALE OF HARDNESS (MOHS)

Agate.....	7.0	Gypsum.....	2.0 <sup>1</sup>
Alabaster.....	1.7	Heavy spar....	3.3
Alum.....	2.0-2.5	Hornblende.....	5.5
Amber.....	2.0-2.5	Iridium.....	6.0
Andalusite.....	7.5	Jasper.....	7.0
Anthracite.....	2.2	Kaolin.....	1.0
Antimony.....	3.3	Lead.....	1.5
Apatite.....	5.0 <sup>1</sup>	Meerschaum.....	2.0-3.0
Aragonite.....	3.5	Mica.....	2.5-3.0
Arsenic.....	3.5	Nickel.....	5.0-5.5
Asphalt.....	1.0-2.0	Onyx.....	7.0
Augite.....	6.0	Opal.....	4.0-6.0
Beryl.....	7.8	Palladium.....	4.8
Bismuth.....	2.5	Platinum.....	4.3
Calamine.....	5.0	Quartz.....	7.0 <sup>1</sup>
Calcite.....	3.0 <sup>1</sup>	Ruby.....	9.0
Copper.....	2.5-3.0	Salt peter.....	2.0
Copperas.....	2.0	Sapphire.....	9.0 <sup>1</sup>
Copper sulphate.....	2.5	Serpentine.....	3.0-4.0
Corundum.....	9.0	Silver.....	2.5-3.0
Diamond.....	10.0 <sup>1</sup>	Spinel.....	8.0
Dolomite.....	3.5-4.0	Stibnite.....	2.0
Emery.....	9.0	Sulphur.....	1.5-2.5
Feldspar.....	6.0 <sup>1</sup>	Talc.....	1.0
Fluorite.....	4.0 <sup>1</sup>	Topaz.....	8.0 <sup>1</sup>
Gold.....	2.5-3.0	Tin.....	2.0-3.0
Granite.....	7.0	Zinc.....	4.0
Graphite.....	0.5-1.0	Zirconium.....	7.8

<sup>1</sup> The materials marked thus (1) are the standards on this scale. The hardness is determined by scratching an unknown with these standards. One can scarcely determine within half a point what the hardness is. The finger nail may be assumed at about 2.5, and a knife blade at 6.5.

"Among the various methods which have been proposed for the measurement of hardness, it seems probable that the BRINNELL ball-test, measuring indentation hardness, is probably that one which most nearly approaches our fundamental ideal of constituting a measure of a single definite property. In this case the test probably measures a group of properties of a fairly simple type. That this is the case may be inferred from the fact that tests with balls of different diameter can be rendered fairly comparable."

$$\text{Hardness} = \frac{\text{load in kg.}}{\text{area of concavity of indentation}} \times \sqrt[5]{\text{radius of ball.}}$$

The BRINNELL hardness number is nearly proportional to the ultimate stress determined by tensile tests. On the other hand, ball-hardness number is not a safe guide as to the power to resist abrasion.<sup>1</sup> A better test for resistance to wear is probably that of the DERIHON machine, in which the edge of a hard steel disc revolving in oil is pressed against the test specimen.<sup>2</sup> Some comparative BRINNELL numbers are given on p. 235.

BOTTONE'S SCALE OF HARDNESS<sup>1</sup>

Diamond...	3010	Copper.....	1360	Iridium.....	984	Tin.....	651
Manganese..	1456	Palladium...	1200	Gold.....	979	Lead.....	570
Cobalt.....	1450	Platinum...	1107	Aluminum....	821	Thallium...	565
Nickel.....	1410	Zinc.....	1077	Cadmium....	760	Calcium....	405
Iron.....	1375	Silver.....	990	Magnesium...	726	Sodium.....	400
						Potassium...	230

<sup>1</sup> *Am. Jour. Sci.*, 1874, Vol. 150, p. 644.

LATENT HEAT OF EVAPORATION<sup>1</sup>

Air.....	51.0	Mercury.....	68.0
Aluminum.....	2227.0	Magnesium.....	1700
Arsenic (sublimation).....	60.0	Nitric anhydride (N <sub>2</sub> O <sub>5</sub> )...	44.81
Antimony (calculated).....	359.0	Nitrous oxide (N <sub>2</sub> O).....	100.6
Acid, acetic.....	121.0	Nitric acid.....	115.08
formic.....	120.7	Oxygen.....	50.9
Alcohol, ethyl.....	208.92	Phosphorus.....	287.0
methyle.....	263.86	Potassium.....	592.0
Ammonia (liquid NH <sub>3</sub> ).....	341.0	Selenium.....	140.0
Arsenic chloride.....	53.6	Silicon (calculated).....	1262.0
Bromine.....	49.6	Silver.....	715.0
Cadmium.....	398.0	Sodium.....	1015.0
Carbon dioxide.....	49.32	Sulphur (at 445°C.).....	458.0
Carbon disulphide.....	86.67	Sulphur dioxide.....	94.56
Carbon (calculated).....	38.37	Sulphuric acid.....	122.1
Chlorine.....	61.9	Sulphuric anhydride.....	147.5
Copper.....	858.0	Stannic chloride.....	30.53
Hydrogen.....	123.0	Tin.....	271.0
Iodine.....	24.0	Water.....	538.0
Iron.....	1595.0	Zinc.....	425.0
Lithium (calculated).....	2.54		

<sup>1</sup> Latent heats of evaporation (and of fusion) are the B.t.u. required to evaporate (or fuse) a pound of material without rise of temperature. In metric units it is the large calories per kilogram.

<sup>1</sup> ROSENHAIN, "Introduction to Physical Metallurgy."

<sup>2</sup> Also see p. 81 for Charpy test.

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### LATENT HEATS OF FUSION (CALORIES PER GRAM) AND MELTING POINTS, °C.

	Deg. C.	Cal. per gram		Deg. C.	Cal. per gram
Aluminum.....	657	86.5	Magnesium.....	650	71.8
Antimony.....	630	39.4	Mercury....	-38.7	2.79
Beryllium.....		30.5	Monel metal.		68.0
Bismuth.....	270	10.3	Nickel....	1450	75.8
Cadmium.....	321	11.1	Palladium.....	1550	36.3
Cæsium.....	28.5	37.6	Phosphorus ..	44.1	5.13
Calcium.....	810	52.6	Platinum.....	1755	26.9
Cobalt.....	1480	68.0	Potassium.....	63.5	14.7
Copper.....	1084	41.7	Rubidium.....	38.7	8.86
Gallium.....	30	19.1	Selenium.....	218.5	13.0
Gold.....	1064	15.9	Silicon.....	1420	127.7
Ice.....	0	79.77	Silver.....	961	26.0
Iodine.....	114	11.7	Sodium.....	97.6	27.3
Iridium.....	2300	26.1	Steel.....		20.0
Iron, electrolytic.	1530	49.2	Sulphur.....	116.5 <sup>1</sup>	27.3 <sup>1</sup>
Iron, gray.....	1375	33.0	Tellurium.....	451	19.0
Iron pig (4.3 C)		67.6	Thallium ..	302	7.2
Iron, white.....	1075	23.0	Tin.....	232	13.5
Lead.....	327	5.62	Zinc.....	419	25.5

<sup>1</sup> When molten sulphur changes to a leathery solid at 160°C., there is 13.1 cal. per gram given out.

### Latent Heat of Fusion of Compounds

#### Oxides

Al <sub>2</sub> O <sub>3</sub> .....	50.9	SiO <sub>2</sub> .....	76.1
H <sub>2</sub> O.....	79.73	TiO <sub>2</sub> .....	35.8

#### Halides and Sulphides

AsCl <sub>3</sub> .....	69.74	PbCl <sub>2</sub> .....	20.90
CuCl.....	22.4	PbS.....	104
MnCl <sub>2</sub> .....	49.37	SnCl <sub>4</sub> .....	46.84
PbBr <sub>2</sub> .....	12.34	ZnCl <sub>2</sub> .....	54.1

#### Nitrates

KNO <sub>3</sub> .....	48.90	NaNO <sub>3</sub> .....	64.87
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#### Silicates

Al-calcium silicate (anorthite)	CaAl <sub>2</sub> Si <sub>2</sub> O <sub>8</sub>	100
Al-potassium silicate (orthoclase)	KAlSi <sub>3</sub> O <sub>8</sub>	100
Al-potassium silicate (microcline)	KAlSi <sub>3</sub> O <sub>8</sub>	83
Calcium silicate (wollastonite)	CaSiO <sub>3</sub>	100
Ca-magnesium silicate (malacolite)	Ca <sub>2</sub> MgSi <sub>4</sub> O <sub>12</sub>	94
Ca-magnesium silicate (diopside)	CaMgSi <sub>2</sub> O <sub>6</sub>	100
Magnesium silicate (enstatite)	MgSiO <sub>3</sub>	125
Magnesium silicate (olivine)	Mg <sub>2</sub> SiO <sub>4</sub>	130
Iron silicate (fayalite)	Fe <sub>2</sub> SiO <sub>4</sub>	85

The first table on the page is recalculated from the values given in "International Critical Tables," with additional values from KAYE and LABY'S "Chemical and Physical Constants." The remaining tables are from J. W. RICHARDS, "Metallurgical Calculations."



SPECIFIC HEATS OF NON-METALS AND ALLOYS<sup>1</sup>

Material	Specific heat	Material	Specific heat
<b>Solids:</b>		<b>Liquids:</b>	
Asbestos (20°-100°)...	0.20	Alcohol, ethyl (40°)...	0.65
Brass (red).....	0.09	Alcohol methyl (12°) ..	0.60
Brass (yellow).....	0.088	Benzene, C <sub>6</sub> H <sub>6</sub> (10°)	0.340
Brickwork.....	About 0.2	Benzine	0.45
Carbon, graphite	0.16	Benzol, (19°-30°) .....	0.4158
Clay .....	0.19	Gasoline.....	0.53
Coal .....	0.24	Glycerine (18°-50°) .....	0.58
Fluorspar (30°)	0.21	Hydrochloric (HCl	
German silver (0°-100°).	0.085	+ 10H <sub>2</sub> O) (18°).....	0.749
Glass, crown (10°-50°)	0.16-0.20	Hydrogen (253°).....	6.00
Glass, flint (10°-50°) ..	0.12	Kerosene .....	0.47
Granite (20°-100°)	0.19-0.20	Lead (molten).....	0.03
Ice .....	0.502	Mercury (5°-36°) ..	0.0333
Monel metal (20°-400°) ..	0.127	Nitric (HNO <sub>3</sub> + 10H <sub>2</sub> O)	
Iron, cast .....	0.13	(18°)	0.768
Iron, wrought .....	0.11	Nitrogen (-208° to -196°)	0.43
Marble (18°) .....	0.21	Oil, olive (7°) .....	0.47
Quartz (0°) .....	0.174	Oxygen (-200° to -183°)	0.35
Quartz (350°) .....	0.279	Sea water (17°) .....	0.94
Sand (20°-100°) .....	0.19	Sulphur (119°-147°)	0.2346
Steel .....	0.12	Sulphuric (H <sub>2</sub> SO <sub>4</sub> ) (16°-20°)	0.3315
Stone .....	About 0.2	Sulphuric (H <sub>2</sub> SO <sub>4</sub>	
Wood .....	0.45-0.65	+ 5H <sub>2</sub> O) (16°-20°)	0.5764
		Turpentine (18°) ..	0.42

The specific heat of a substance is the number of B.t.u.'s required to raise the temperature of a pound of the substance 1°F or the number of large calories required to raise the temperature of a kilogram of the substance 1°C. There is much discordant data on the subject and several tables are given. The user is advised to look over all the tables, as the data is given in several forms.

<sup>1</sup> From PIERCE and CARVER'S, "Formulas and Tables for Engineers," with some additions from other authorities. For all the elements, see the tables on page 244 and 246.

SPECIFIC HEATS OF SOME METALS<sup>1</sup>

Metal	Specific heat		As a gas	Metal	Specific heat		As a gas
	At about 15°C.	At about melting point			At about 15°C.	At about melting point	
Ag....	0.055	0.076	0.046	Mn....	0.122		
Al....	0.167	0.308	0.1852	Mo....	0.066		
Bi....	0.030	0.030		Na....	0.293		0.2174
Cb....	0.068			Ni....	0.109	0.161	
Cd....	0.054	0.062	0.0446	Os....	0.031		
Co....	0.106	0.204		P....			0.064
Cu....	0.091	0.118		Pb....	0.030	0.034	
Fe....	0.116	0.162		Pt....	0.032	0.046	
Hg....	0.033	0.032	0.025	Sr....	0.0735		
Ir....	0.030	0.040		Sb....	0.048	0.064	0.416
K....	0.166	0.23	0.128	Si....			0.107
La....	0.941	0.975	0.714	Sn....	0.055	0.059	0.424
Mg....	0.246		0.2084	Tl....	0.03355		0.024
W....	0.035			Zn....	0.093	0.122	0.076

<sup>1</sup> The first two columns are from HOFMAN'S "General Metallurgy," the values for the gaseous state are from J. W. RICHARDS' "Metallurgical Calculations."

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SPECIFIC HEATS OF THE ELEMENTS<sup>1</sup>

Calories per gram per degree Centigrade

Substance <sup>1</sup>	Temperature <sup>1</sup>	Sp. heat <sup>1</sup>	Substance <sup>1</sup>	Temperature <sup>1</sup>	Sp. heat <sup>1</sup>
Aluminum....	-182°-15°	0.168	Lead..	300°	0.0338
	17°-100°	0.217		Molten	0.0402
	600°	0.282	Lithium....	0°-19°	0.837
Antimony.....	-186°--79°	0.0462		0°-100°	1.093
	1°-20°	0.0503	Magnesium	-186°--79°	0.189
	Molten			17°-100°	0.248
Arsenic: Cryst.	632°-830°	0.0603		225°	0.281
Amorph.....	0°-100°	0.0822	Manganese.	-188°-20°	0.093
Barium.....	21°-65°	0.076		14°-97°	0.189
	-185°-20°	0.068	Mercury..	-213°	0.0266
Beryllium.....	0°-100°	0.05		0°-80°	0.0331
Bismuth.....	0°-100°	0.425	Molybdenum	-185°-20°	0.063
	22°-100°	0.0284		15°-91°	0.072
	Molten	0.0304	Nickel	-186°-18°	0.086
		0.0363		18°-100°	0.109
Bromine: Solid	-78°--20°	0.084	Nitrogen, liq.	-208--196°	0.43
Liquid.....	13°-45°	0.107	Osmium.....	19°-98°	0.031
Gas.....	150°-230°	0.0570	Palladium....	18°-100°	0.059
Boron, amorph.	0°-100°	0.307	Phosphorus:		
Cadmium.....	-186°--79°	0.050	Yellow.....	-78°-10°	0.17
	Pure 18°-99°	0.055	Yellow.....	13°-36°	0.202
Cæsium.....	0°-26°	0.048	Liquid.....	49°-98°	0.205
Calcium.....	0°-20°	0.145	Red.....	15°-98°	0.17
Carbon.....	0°-20°	0.145	Platinum....	-186°-18°	0.0293
Gas carbon....	24°-68°	0.204		18°-100°	0.0324
Charcoal.....	0°-24°	0.165		1230°	0.0461
Charcoal.....	0°-224°	0.238	Potassium...	-78°-23°	0.166
Graphite.....	-50°	0.114	Rhodium....	10°-97°	0.058
Graphite.....	11°	0.160	Ruthenium...	0°-100°	0.061
Graphite.....	202°	0.297	Scenium:		
Graphite.....	977°	0.467	Cryst.....	22°-62°	0.084
Diamond.....	11°	0.113	Amorph.....	18°-38°	0.095
Cerium.....	0°-100°	0.045	Silicon, cryst	-185°-20°	0.123
Chlorine, liquid	0°-24°	0.226		57°	0.183
Chromium.....	-200°	0.067		232°	0.203
	0°	0.104	Silver.....	-186°--79°	0.496
	17°-10°	0.110		15°-100°	0.056
	400°	0.133		427°	0.059
Cobalt.....	-182°-15°	0.082	Sodium: Solid	-185°-20°	0.234
	15°-100°	0.103	Solid.....	10°	0.297
	15°-630°	0.123	Liquid....	128°	0.333
Copper.....	-192° 20°	0.0798	Sulphur:		
	20°-100°	0.0936	Rhombic...	17°-45°	0.163
	900°	0.118	Liquid.....	160°-233°	0.300
	Molten	0.1318	Tantalum	-185°-20°	0.033
Didymium....	0°-100°	0.046		58°	0.036
Gallium, solid	12°-23°	0.079	Tellurium...	15°-100°	0.0483
Liquid.....	12°-119°	0.080	Thallium....	-192°-20°	0.0300
Germanium....	0°-100°	0.074		17°-100°	0.0335
Gold.....	-185°-20°	0.035	Thorium...	0°-100°	0.028
	18°-990°	0.0303	Tin.....	-186°--79°	0.0486
	Molten	0.0358		19°-99°	0.0552
Indium.....	0°-100°	0.057		Molten	
Iodine.....	9°-98°	0.054		240°	0.064
	Vapor	0.03489	Titanium....	-185°-20°	0.082
Iridium.....	-186°-18°	0.0282		0°-100°	0.113
	18°-100°	0.0323		0°-440°	0.162
Iron.....	-192°-20°	0.089	Tungsten....	-185°-20°	0.036
	20°-100°	0.119		20°-100°	0.034
	2-5°	0.137	Uranium.....	0°-98°	0.028
	0°-1100°	0.153	Vanadium....	0°-100°	0.115
	Molten	0.25	Zinc.....	+233°	0.0268
Lanthanum....	0°-100°	0.045		-192°-20°	0.084
Lead.....	-253°	0.120		20°-100°	0.093
	-192°-20°	0.0293		300°	0.104
	15°-100°	0.0309	Zirconium....	0°-100°	0.068

<sup>1</sup> See also the table on p. 246.

SPECIFIC HEAT OF FERRIC OXIDE, ( $\text{Fe}_2\text{O}_3$ )

Temp., deg. C.	Heat capacity, cal. per gram	Temp., deg. C.	Heat capacity, cal. per gram
0	0.150	260	0.216
20	0.158	280	0.2205
40	0.164	300	0.225
60	0.1695	320	0.2295
80	0.175	340	0.234
100	0.180	360	0.2385
120	0.1845	380	0.2525
140	0.189	400	0.2645
160	0.1935	450	0.280
180	0.198	500	0.2955
200	0.2025	550	0.311
220	0.207	600	0.326
240	0.2115	650	0.342

There is an allotropic transformation of  $\text{Fe}_2\text{O}_3$  at  $360^\circ\text{C}.$ , absorbing 4.85 cal. per gram. There are also various transitions between  $650^\circ\text{C}.$  and  $825^\circ\text{C}.$  which absorb 41.8 cal. per gram. (G. G. BROWN and C. C. FURNAS, *Trans. A. I. C. E.*, 1923.)  $\text{Fe}_2\text{O}_3$  melts at about  $1579^\circ\text{C}.$  EDITOR.

There is an allotropic transformation of Ni at from  $310$ – $345^\circ\text{C}.$ , depending on impurities. Nickel is magnetic below, non-magnetic above this transformation point. The latent heat of this change is 4.64 cal. per gram.

## Data on Sulphur

$S\alpha$ (rhombic) changes to  $S\beta$ (monoclinic) at  $94.5^\circ\text{C}.$  and absorbs 81 cal. per gram atom.

$S\alpha$ (monoclinic) melts at  $116.5^\circ\text{C}.$  to  $S\lambda$ (liquid).

$S\lambda$ (liquid) changes a leathery solid ( $S\mu$ ) at  $160^\circ\text{C}.$

The change from  $S_8$  to  $S_2$  (both gaseous) at  $1000^\circ\text{C}.$  absorbs 5850 cal. per gram atom.

The specific heats are as follows:

$S\alpha$  0 –  $95^\circ$  0.1751

$S\alpha$  17 –  $45^\circ$  0.163

$S\lambda$  119 –  $147^\circ$  0.2346

$S\mu$  160 –  $264^\circ$  0.300

The specific heat of carbon disulphide at  $100^\circ\text{C}.$  is 0.2617.

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### SPECIFIC HEATS OF METALS FOR $t^{\circ}$ CENTIGRADE<sup>1</sup>

Aluminum.....	0.2220	+ 0.00005 <i>t</i>
Antimony.....	0.04864	+ 0.0000084 <i>t</i>
Beryllium.....	0.3756	+ 0.00106 <i>t</i>
Boron.....	0.22	+ 0.00035 <i>t</i>
Carbon (under 250°)...	0.1567	+ 0.00036 <i>t</i>
Carbon (250°-1000°)...	0.2142	+ 0.000166 <i>t</i>
Carbon (above 1,000°)...	0.5	— (120 ÷ <i>t</i> )
Nickel (up to 230°)...	0.10836	+ 0.00002233 <i>t</i>
Potassium.....	0.1858	+ 0.00008 <i>t</i>
Silicon.....	0.17	+ 0.00009 <i>t</i>
Sodium.....	0.2932	+ 0.00019 <i>t</i>
Titanium.....	0.978	+ 0.000147 <i>t</i>
Zinc.....	0.0906	+ 0.000044 <i>t</i>
Bismuth.....	0.0285	+ 0.00002 <i>t</i>
Bromine.....	0.105	+ 0.0011 <i>t</i>
Copper.....	0.0917	+ 0.000048 <i>t</i>
Cadmium.....	0.0546	+ 0.000012 <i>t</i>
Iridium.....	0.0317	+ 0.000006 <i>t</i>
Lead.....	0.02925	+ 0.000019 <i>t</i>
Palladium.....	0.0582	+ 0.00001 <i>t</i>
Platinum.....	0.0317	+ 0.000006 <i>t</i>
Silver (to 400°).....	0.555	+ 0.00000943 <i>t</i>
Silver (over 400°).....	0.5758	+ 0.0000044 <i>t</i>
Tin.....	0.0560	+ 0.000044 <i>t</i>

<sup>1</sup> J. W. RICHARDS, "Metallurgical Calculations."

<sup>2</sup> From HOFMAN'S, "General Metallurgy."

### SPECIFIC HEATS OF CHLORIDES

Chlorides	Formula	Range	Specific heat
Ammonium chloride...	NH <sub>4</sub> Cl	23°-100°	0.3908
Arsenious chloride...	AsCl <sub>3</sub> (solid)	14°-98.3°	0.0896
	AsCl <sub>3</sub> (gas)	159°-268°	0.1122
Barium chloride...	BaCl <sub>2</sub>	14°-98°	0.0896
Calcium chloride...	CaCl <sub>2</sub>	23°-99°	0.1730
Chromium chloride...	CrCl <sub>2</sub>	.....	0.1430
Cuprous chloride...	Cu <sub>2</sub> Cl <sub>2</sub>	17°-98°	0.1383
Lead chloride...	PbCl <sub>2</sub>	{ 20°-100° 160°-380°	{ 0.0651 0.707 }
Lithium chloride...	LiCl	13°-97°	0.2821
Magnesium chloride...	MgCl <sub>2</sub>	24°-100°	0.1946
Manganese chloride...	MnCl <sub>2</sub>	.....	0.1425
Mercurous chloride...	HgCl	7°-99°	0.0521
Mercuric chloride...	HgCl <sub>2</sub>	13°-98°	0.0689
Potassium chloride...	KCl	14°-99°	0.1730
Silver chloride.....	AgCl	160°-380°	0.0978
Sodium chloride.....	NaCl	15°-98°	0.2140
Strontium chloride...	SrCl <sub>2</sub>	13°-98°	0.1199
Titanium chloride...	TiCl <sub>4</sub> (solid)	13°-99°	0.1881
	TiCl <sub>4</sub> (gas)	163°-271°	0.1290
Tin (ous).....	SnCl <sub>2</sub>	20°-99°	0.1016
-(ic).....	SnCl <sub>4</sub> (solid)	14°-98°	0.1476
	SnCl <sub>4</sub> (gas)	149°-273°	0.0939
Zinc chloride.....	ZnCl <sub>2</sub>	21°-99°	0.1362

SPECIFIC HEATS OF THE OXIDES<sup>1</sup>

Oxide	Formula	Range	Specific heat
Beryllium oxide..	Be <sub>2</sub> O <sub>3</sub>	0°-100°	0.2471
Boron oxide..	B <sub>2</sub> O <sub>3</sub>	16°-98°	0.2374
Antimonious oxide	Sb <sub>2</sub> O <sub>3</sub>	18°-100°	0.0927
Alumina.....	Al <sub>2</sub> O <sub>3</sub>	0°-1200°	0.2081 + 0.0000876t
Alumina.....	Al <sub>2</sub> O <sub>3</sub>	above 2200°	0.5935
Arsenious oxide..	As <sub>2</sub> O <sub>3</sub>	13°-97°	0.1276
Calcium oxide..	CaO	0°-t°	0.1715 + 0.00007t
Chromium oxide..	Cr <sub>2</sub> O <sub>3</sub>	10°-99°	0.1796
Ferric oxide.....	Fe <sub>2</sub> O <sub>3</sub>	0°-t°	0.1456 + 0.000188t
Ferroso-ferric oxide	Fe <sub>3</sub> O <sub>4</sub>	0°-t°	0.1447 + 0.000188t
Magnesium oxide..	MgO	24°-100°	0.2440
Magnesium hydrate	Mg(OH) <sub>2</sub>	19°-50°	0.312
Manganese oxide..	MnO	13°-98°	0.157
Manganese sesquioxide..	Mn <sub>2</sub> O <sub>3</sub>	15°-99°	0.162
Manganese sesquioxide, hydrated .....	Mn <sub>2</sub> O <sub>3</sub> .H <sub>2</sub> O	21°-52°	0.1760
Manganese peroxide..	MnO <sub>2</sub>	17°-48°	0.1590
Nickel oxide..	NiO	13°-98°	0.1588
Silica.....	SiO <sub>2</sub>	0°-1200°	0.1833 + 0.000077t
Mercuric oxide	HgO	5°-98°	0.0518
Molybdic oxide	MoO <sub>3</sub>	21°-52°	0.1540
Lead oxide..	PbO	22°-98°	0.0512
Bismuth oxide..	Bi <sub>2</sub> O <sub>3</sub>	20°-98°	0.0605
Thoric oxide..	Th <sub>2</sub> O <sub>3</sub>	0°-100	0.0548
Tin oxide.....	SnO <sub>2</sub>	16°-98°	0.0936
Titanic oxide..	TiO <sub>2</sub>	0°-200°	0.1790
Tungstic oxide	WO <sub>3</sub>	8°-98°	0.0798
Zirconium oxide	ZrO <sub>2</sub>	0°-100°	0.1076
Zinc oxide.....	ZnO	0°-1000°	0.1212 + 0.0000315t
Cuprous oxide	Cu <sub>2</sub> O	19°-51°	0.1110
Cupric oxide..	CuO	12°-98°	0.1420
Columbic oxide..	Cb <sub>2</sub> O <sub>5</sub>	0°-t°	0.1037 + 0.00007t
Ferrous oxide...	FeO	..	0.1460(a)
Potassium oxide..	K <sub>2</sub> O	..	0.1390(a)
Sodium oxide..	Na <sub>2</sub> O	..	0.2250(a)
Lithium oxide..	Li <sub>2</sub> O	..	0.4430(a)

(a) Theoretical results, according to Voigt.

<sup>1</sup> J. W. RICHARDS, "Metallurgical Calculations," Vol. II.

## SPECIFIC HEATS OF SULPHATES

Sulphates	Formula	Range	Specific heat
Barium sulphate..	BaSO <sub>4</sub>	10°-98°	0.1128
Calcium sulphate..	CaSO <sub>4</sub>	13°-98°	0.1965
Copper sulphate..	CuSO <sub>4</sub>	23°-100°	0.1840
Lead sulphate....	PbSO <sub>4</sub>	20°-99°	0.0827
Magnesium sulphate	MgSO <sub>4</sub>	25°-100°	0.2250
Manganese sulphate	MnSO <sub>4</sub>	21°-100°	0.1820
Nickel sulphate....	NiSO <sub>4</sub>	15°-100°	0.2160
Potassium acid sulphate...	HKSO <sub>4</sub>	19°-51°	0.2440
Potassium sulphate	..	15°-98°	0.1901
Sodium sulphate	..	17°-98°	0.2312
Strontium sulphate	..	22°-99°	0.1428
Zinc sulphate	..	22°-100°	0.1740

## SPECIFIC HEATS OF NITRATES

Nitrates	Formula	Range	Specific heat
Ammonium nitrate.....	$\text{NH}_4\text{NO}_3$	14°-31°	0.4550
Barium nitrate.....	$\text{Ba}(\text{NO}_3)_2$	13°-98°	0.1623
Lead nitrate.....	$\text{Pb}(\text{NO}_3)_2$	17°-100°	0.1173
Potassium nitrate.....	$\text{KNO}_3$	13°-98°	0.2387
Silver nitrate.....	$\text{AgNO}_3$	16°-99°	0.1435
Sodium nitrate.....	$\text{NaNO}_3$	14°-98°	0.2782
Strontium nitrate..	$\text{Sr}(\text{NO}_3)_2$	17°-47°	0.1810
Sodium-potassium nitrate.....	$\text{KNa}(\text{NO}_3)_2$	15°-100°	0.2350
Sodium nitrate (fused).....	$\text{NaNO}_3$ (liquid)	320°-430°	0.4130
Potassium nitrate (fused).....	$\text{KNO}_3$ (liquid)	350°-435°	0.3319

## SPECIFIC HEATS OF CARBONATES

Carbonates	Formula	Range	Specific heat
Barium carbonate.....	$\text{BaCO}_3$	11°-99°	0.1104
Calcium carb. (calcite).....	$\text{CaCO}_3$	20°-100°	0.2086
Calcium carb. (aragonite).....	$\text{CaCO}_3$	18°-99°	0.2085
Calcium carb. (marble).....	$\text{CaCO}_3$	23°-98°	0.2099
Calcium-magnesium (dolomite).....	.....	20°-100°	0.2179
Iron (siderite).....	$\text{FeCO}_3$	9°-98°	0.1935
Iron-magnesium.....	$\text{Mg}_7\text{Fe}_2(\text{CO}_3)_9$	20°-100°	0.2270
Lead (cerussite).....	$\text{PbCO}_3$	16°-47°	0.0791
Potassium carbonate.....	$\text{K}_2\text{CO}_3$	23°-99°	0.2162
Sodium carbonate.....	$\text{Na}_2\text{CO}_3$	16°-98°	0.2728
Strontium carbonate.....	$\text{SrCO}_3$	8°-98°	0.1475

## SPECIFIC HEATS OF CHROMATES

Chromates	Formula	Range	Specific heat
Lead chromate.....	$\text{PbCrO}_4$	19°-50°	0.0900
Iron chromate.....	$\text{FeCrO}_4$	19°-50°	0.1590
Potassium bichromate.....	$\text{K}_2\text{Cr}_2\text{O}_7$	16°-98°	0.1894
Potassium chromate.....	$\text{K}_2\text{CrO}_4$	19°-98°	0.1851

## SPECIFIC HEATS OF BORATES

Borates	Formula	Range	Specific heat
Lead diborate.....	$\text{PbB}_2\text{O}_4$	15°-98°	0.905
Lead tetraborate.....	$\text{PbB}_4\text{O}_7$	18°-99°	0.2198
Potassium diborate.....	$\text{K}_2\text{B}_2\text{O}_4$	16°-98°	0.2048
Potassium tetraborate.....	$\text{K}_2\text{B}_4\text{O}_7$	18°-99°	0.2198

## SPECIFIC HEATS OF BROMIDES, IODIDES AND FLUORIDES

Bromides	Formula	Range	Specific heat
Lead bromide. ....	PbBr <sub>2</sub>	16°-98° 190°-430°	0.0532 0.0532
Potassium bromide. ....	KBr	16°-98°	0.1132
Silver bromide. ....	AgBr	15°-98°	0.0739
Sodium bromide. ....	NaBr	.....	0.1384
Cuprous iodide. ....	CuI	20°-99°	0.0819
Lead iodide. ....	PbI <sub>2</sub>	14°-98°	0.0427
Mercurous iodide. ....	HgI	17°-99°	0.0395
Mercuric iodide. ....	HgI <sub>2</sub>	18°-99°	0.0420
Potassium iodide. ....	KI	20°-99°	0.0819
Silver iodide. ....	AgI	15°-264°	0.577
Sodium iodide. ....	NaI	16°-99°	0.0868
Calcium fluoride. ....	CaF <sub>2</sub>	15°-99°	0.2154
Sodium-aluminum fluoride. ....	Na <sub>3</sub> AlF <sub>6</sub>	16°-99°	0.2522

## SPECIFIC HEATS OF PHOSPHATES

Phosphates	Formula	Range	Specific heat
Calcium acid phosphate. ....	CaP <sub>2</sub> O <sub>6</sub>	15°-98°	0.1092
Calcium phospo-fluoride (apatite)	3Ca <sub>3</sub> P <sub>2</sub> O <sub>8</sub> ·CaF <sub>2</sub>	15°-99°	0.1903
Lead, tribasic diphosphate	Pb <sub>3</sub> P <sub>2</sub> O <sub>8</sub>	11°-98°	0.0798
Lead pyrophosphate. ....	Pb <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	11°-98°	0.821
Potassium pyrophosphate	K <sub>4</sub> P <sub>2</sub> O <sub>7</sub>	17°-98°	0.1901
Silver phosphate	Ag <sub>3</sub> P <sub>2</sub> O <sub>4</sub>	19°-50°	0.0898
Sodium pyrophosphate.	Na <sub>4</sub> P <sub>2</sub> O <sub>7</sub>	17°-98°	0.2283

## SPECIFIC HEATS OF ALUMINATES, TITANATES, ETC.

Aluminates	Formula	Range	Specific heat
Spinel. ....	MgAl <sub>2</sub> O <sub>4</sub>	15°-47°	0.1940
Chrysoberyl. ....	BeAl <sub>2</sub> O <sub>4</sub>	0°-100°	0.2004
Ilmenite. ....	FeTiO <sub>3</sub>	15°-50°	0.177
Wulfenite. ....	PbMoO <sub>4</sub>	15°-50°	0.083
Scheelite. ....	CaWO <sub>4</sub>	15°-50°	0.097
Wolframite. ....	Fe(Mn)WO <sub>4</sub>	15°-50°	0.098
Potassium permanganate	KMnO <sub>4</sub>	15°-15°	0.179
Potassium chlorate	KClO <sub>3</sub>	10°-100°	0.210
Glass. ....	Ca, K, SiO <sub>3</sub>	14°-99°	0.1977
Glass, flint. ....	.....	10°-50°	0.177
Glass, crown. ....	.....	10°-50°	0.161

## COMPOUND SULPHIDES

Sulphides	Formula	Range	Specific heat
Bornite	Cu <sub>5</sub> FeS <sub>4</sub>	10°-100°	0.1177
Bournonite. ....	PbCuSbS <sub>3</sub>	10°-100°	0.0730
Cobaltite. ....	CoAsS	15°-99°	0.0991
Chalcopyrite. ....	CuFeS <sub>2</sub>	14°-98°	0.1310
Mispickel. ....	FeAsS. ....	10°-100°	0.1080
Proustite. ....	Ag <sub>3</sub> AsS <sub>3</sub>	10°-100°	0.0807
Pyrrargyrite. ....	Ag <sub>3</sub> SbS <sub>3</sub>	10°-100°	0.0757
Tetrahedrite. ....	Cu <sub>4</sub> Sb <sub>2</sub> S <sub>7</sub>	10°-100°	0.0987

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## SPECIFIC HEATS OF SULPHIDES

Sulphides	Formula	Range	Specific heat
Antimony sulphide.....	Sb <sub>2</sub> S <sub>3</sub>	23°-99°	0.0840
Arsenic sulphide.....	As <sub>2</sub> S	20°-100°	0.1111
Arsenic sulphide.....	As <sub>2</sub> S <sub>3</sub>	20°-100°	0.1132
Bismuth sulphide.....	Bi <sub>2</sub> S <sub>3</sub>	11°-99°	0.0600
Cobalt sulphide.....	CoS	15°-98°	0.1251
Copper sulphide.....	Cu <sub>2</sub> S	9°-97°	0.1212
	Cu <sub>3</sub> S	0°-t°	0.1126+
			0.000094
Ferrous sulphide.....	FeS	17°-98°	0.1357
Iron sulphide.....	Fe <sub>7</sub> S <sub>8</sub>	20°-100°	0.1602
Iron pyrites.....	FeS <sub>2</sub>	19°-98°	0.1301
Lead sulphide.....	PbS	16°-98°	0.0509
Manganese sulphide.....	MnS	10°-100°	0.1392
Mercury sulphide.....	HgS	14°-98°	0.0512
Molybdenum sulphide.....	MoS <sub>2</sub>	20°-100°	0.1233
Nickel sulphide.....	NiS	15°-98°	0.1281
Silver sulphide.....	Ag <sub>2</sub> S	7°-98°	0.0746
	Ag <sub>3</sub> S	0°-t°	0.0685+
			0.000054
Zinc sulphide.....	ZnS	15°-98°	0.1230
Stannous sulphide.....	SnS	13°-98°	0.0837
Stannic sulphide.....	SnS <sub>2</sub>	12°-95°	0.1193

## SPECIFIC HEATS OF ARSENIDES AND ANTIMONIDES

Antimonides	Formula	Range	Specific heat
Domeykite.....	Cu <sub>2</sub> As	10°-100°	0.0949
Dyscrasite.....	Ag <sub>2</sub> Sb	10°-100°	0.0558
Löllingite.....	FeAs <sub>2</sub>	10°-100°	0.0864
Smaltite.....	CoAs <sub>2</sub>	10°-100°	0.0830

## SPECIFIC HEATS OF SILICATES

Silicates	Formula	Range	Specific heat
Aluminum silicate (topaz).....	Al <sub>2</sub> Si(F)O <sub>6</sub>	12°-100°	0.1997
Al-calcium silicate (anorthite).....	CaAl <sub>2</sub> Si <sub>2</sub> O <sub>8</sub>	0°-100°	0.189
	Ca <sub>2</sub> Al <sub>2</sub> Si <sub>2</sub> O <sub>8</sub>	0°-1200°	0.294
Al-beryllium silicate (beryl).....	BeAl <sub>2</sub> Si <sub>2</sub> O <sub>6</sub>	12°-100°	0.2066
Al-potassium silicate (microcline).....	KAlSi <sub>3</sub> O <sub>8</sub>	20°-100°	0.197
Al-potassium silicate (orthoclase).....	KAlSi <sub>3</sub> O <sub>8</sub>	20°-100°	0.1877
Calcium silicate (wollastonite).....	CaSiO <sub>3</sub>	0°-100°	0.179
	CaSiO <sub>2</sub>	0°-1200°	0.288
Ca-magnesium silicate (diopside).....	CaMgSi <sub>2</sub> O <sub>6</sub>	0°-100°	0.194
	CaMgSi <sub>2</sub> O <sub>6</sub>	0°-1200°	0.281
Ca-magnesium silicate (malacolite).....	Ca <sub>3</sub> MgSi <sub>4</sub> O <sub>12</sub>	0°-100°	0.186
	Ca <sub>3</sub> MgSi <sub>4</sub> O <sub>12</sub>	0°-1200°	0.264
Iron silicate (fayalite).....	Fe <sub>2</sub> SiO <sub>4</sub>	0°-100°	0.170
Iron-aluminum (garnet).....	Fe <sub>3</sub> Al <sub>2</sub> Si <sub>3</sub> O <sub>12</sub>	16°-100°	0.1758
Magnesium silicate (enstatite).....	MgSiO <sub>3</sub>	0°-100°	0.206
	MgSiO <sub>3</sub>	0°-1200°	0.301
Magnesium silicate (olivine).....	Mg <sub>2</sub> SiO <sub>4</sub>	0°-100°	0.2200
Zirconium silicate (zircon).....	ZrSiO <sub>4</sub>	15°-100°	0.1456
Basalt.....		20°-470°	0.1990
Beasmer slag.....		14°-99°	0.1691
Granite.....		20°-524°	0.2290



**SPECIFIC HEAT OF WATER<sup>1</sup>**  
(Defining specific heat at 32° to 33°F. as unity)

Temperature, deg. F.	Specific heat	Temperature, deg. F.	Specific heat	Temperature, deg. F.	Specific heat
32	1.0000	176	1.0089	320	1.0294
50	1.0005	194	1.0109	338	1.0328
68	1.0012	212	1.0130	356	1.0364
86	1.0020	230	1.0153	374	1.0407
104	1.0030	248	1.0177	392	1.0440
122	1.0042	266	1.0204	410	1.0481
140	1.0056	284	1.0232	428	1.0524
158	1.0072	302	1.0262	446	1.0568

<sup>1</sup> From "The Petroleum Year Book, 1914."

**SPECIFIC HEAT OF WATER<sup>2</sup>**  
(Defining specific heat at 16° to 17° as unity)

Temperature, deg. C.	Specific heat	Thermal capacity, 0° - t°	Temperature, deg. C.	Specific heat	Thermal capacity, 0° - t°
0	1.00940	0.00000	25	0.99806	25.05131
1	1.00855	1.00898	26	0.99795	26.04932
2	1.00770	2.01710	27	0.99784	27.04720
3	1.00690	3.02440	28	0.99774	28.04499
4	1.00610	4.03090	29	0.99766	29.04269
5	1.00530	5.03660	30	0.99759	30.04031
6	1.00450	6.04150	31	0.99752	31.03786
7	1.00390	7.04570	32	0.99747	32.03536
8	1.00330	8.04930	33	0.99742	33.03280
9	1.00276	9.05233	34	0.99738	34.03020
10	1.00230	10.05486	35	0.99735	35.02757
11	1.00185	11.05694	36	0.99733	36.02491
12	1.00143	12.05858	37	0.99732	37.02224
13	1.00100	13.05980	38	0.99732	38.01956
14	1.00064	14.06062	39	0.99733	39.01689
15	1.00030	15.06109	40	0.99735	40.01422
16	1.00000	16.06124	41	0.99738	41.01159
17	0.99970	17.06109	42	0.99743	42.00899
18	0.99941	18.06064	43	0.99748	43.00644
19	0.99918	19.05994	44	0.99753	44.00395
20	0.99895	20.05900	45	0.99760	45.00152
21	0.99872	21.05783	46	0.99767	46.00916
22	0.99853	22.05645	47	0.99774	47.00686
23	0.99836	23.05490	48	0.99781	48.00464
24	0.99820	24.05318	49	0.99790	49.00250
25	0.99806	25.05131	50	0.99800	50.00045

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## MEAN SPECIFIC HEATS OF GASES

	Under constant pressure 0-300°C.	Under constant volume 0-300°C.	$\gamma$
Air, 20°C	0 2417	0 1684	1 402
Ammonia	0 5356	0 391	1 336
Bromine, 19°-388°	0 0555	0 0429	
Carbon dioxide, 0°	0 2010	0 172	1 30
Carbon disulphide, 86°-190°	0 1596	0 131	1 239
Carbon monoxide, 23°-99°	0 2425	0 1736	1 401
Chlorine	0 1241	0 0928	1 33
Hydrogen	3 4090	2 411	1 42
Methane	0 5929	0 486	1 313
Nitrogen, 0°C	0 2350	0 1727	1 41
Nitrous oxide	0 2262	0 181	1 324
Oxygen	0 2175	0 1723	1 41
Sulphur dioxide	0 1544	0 123	(500°) 1 2
Water	0 4805	0 370	1 305
Hydrochloric acid	0 1867		
Acetylene			1 26
Argon, 20°-90°C	0 123		
Iodine, 206°-377°C	0 031		
Nitric oxide, 13°-172°	0 232		1 394
Nitrogen peroxide, 27°-67°	1 625		(150°) 1 31
Sulphuretted hydrogen, 20°-200°	0 245		1 340
Ethane			1 22
Ethylene	0 404		1 264
Benzene, 34°-115°	0 299		(20°) 1 40
Turpentine, 179°-249°	0 506		

## MOLECULAR SPECIFIC HEATS (LEWIS & RANDALL)

These are the ordinary specific heats multiplied by the molecular weight of the gas

$N_2, O_2, HCl, HBr, HI, C_p = 6.5 + 0.0010t$   
 $H_2 \quad C_p = 6.5 + 0.0009t$   
 $Cl_2, Br_2, I_2, C_p = 6.65 + 0.004t$   
 $H_2O, H_2S \quad C_p = 8.81 + 0.0019t + 0.0000222t^2$   
 $CO_2, SO_2 \quad C_p = 7.0 + 0.0071t + 0.0000018t^2$   
 Hydrocarbons =  $4.4 + 1.4n + (0.012 + 0.006n)t^*$

\*  $n$  = number of atoms of C.

## SPECIFIC HEAT OF GASES<sup>1</sup>

(Calories per gram of gas at  $t^\circ C$  (absolute temperature =  $t + 273$ ))

	According to Richards	According to Damour
Nitrogen (to 2000°C.)	0.2405 + 0.0000214t	0.2438 + 0.0000214t
Nitrogen (2000°-4000°C.)	0.2044 + 0.000057t	
Oxygen (to 2000°C.)	0.2104 + 0.0000187t	0.2135 + 0.0000187t
Oxygen (2000°-4000°C.)	0.1788 + 0.00005t	
Water vapour	0.42 + 0.000185t	0.447 + 0.000162t
Carbon dioxide	0.19 + 0.00011t	0.194 + 0.000084t
Sulphur dioxide	0.125 + 0.00061t	
Carbon monoxide	0.2405 + 0.0000214t	0.2438 + 0.0000214t
Hydrogen	3.37 + 0.0003t	3.412 + 0.000300t
Methane		0.381 + 0.0000234t
Hydrogen (2000°-4000°C.)	2.75 + 0.0008t	

<sup>1</sup> SOMMERFELD'S "Cool."

# CONSTANTS FOR CALCULATION OF MOLAL HEAT CAPACITIES OF GASES<sup>1</sup>

$$C_p = a + bT + cT^2 + dT^3$$

Gases	a	b·10 <sup>3</sup>	c·10 <sup>8</sup>	d·10 <sup>6</sup>	Temperature limits °K	Estimated limit of average error, per cent.
Monatomic gases; that is, H, He, A, Hg, Na.....	4.98	.....	.....	.....	.....	<1.0
H <sub>2</sub> , HF { (1) .....	6.85	0.28	0.22	.....	300-2500	1.5
(2) .....	6.50	.90	.....	.....	300-3000	3.0
N <sub>2</sub> , CO, O <sub>2</sub> , NO, HCl, HBr, HI, F <sub>2</sub> { (1) .....	6.76	.606	.13	.....	300-2500	1.5 (F <sub>2</sub> , 5)
(2) .....	6.50	1.00	.....	.....	300-3000	3.0 (F <sub>2</sub> , 5)
Cl <sub>2</sub> , S <sub>2</sub> { (1) .....	5.88	9.35	-7.00	.....	300-700	2.5
(2) .....	8.58	.30	.....	.....	300-2500	5.0
Br <sub>2</sub> , I <sub>2</sub> , K <sub>2</sub> , Hg <sub>2</sub> .....	9.00	.....	.....	.....	300-2000	5.0
H <sub>2</sub> O .....	8.22	.15	1.34	.....	300-2500	1.5
H <sub>2</sub> S .....	7.20	3.60	.....	.....	300-600	5 to 10
CO <sub>2</sub> , SO <sub>2</sub> , (2) CO <sub>2</sub> only { (1) .....	7.70	5.30	-8.3	.....	300-2500	2.5
(2) .....	5.07	16.30	-12.90	3.91	300-1600	1.5
NH <sub>3</sub> .....	6.70	6.30	.....	.....	300-800	1.5
CH <sub>4</sub> .....	5.90	9.60	.....	.....	150-400	5.0

<sup>1</sup> Bureau of Mines, *Tech. Paper 415*.

## SPECIFIC HEAT OF GASES, BY VOLUME<sup>1</sup>

	Cal. per cu. m. of gas, per deg. C.	Lb.-cal. per cu. ft. of gas, per deg. C.
Nitrogen ..	0.303 + 0.000027t	0.0189 + 0.0000017t
Water vapor .....	0.34 + 0.00030t	.....
Carbon dioxide .....	0.37 + 0.00044t	.....
Carbon monoxide .....	0.2575 + 0.000072t	.....
Sulphur dioxide .....	0.444 + 0.00054t	.....
Hydrogen .....	0.303 + 0.000027t	0.0189 + 0.0000017t
Hydrogen (2000°-4000°) ..	0.2575 + 0.000072t	0.0161 + 0.0000045t
Oxygen .....	0.303 + 0.000027t	0.0189 + 0.0000017t

## Total Heat Contained at Melting Point of Metals<sup>1</sup>

The heat is expressed in calories necessary to heat 1 gram of the metal to its melting point from 0°C. The latent heat of fusion is then the difference between the heat in the solid and that in the liquid phases.

Element	Melting point	Heat in solid	Heat in liquid	Latent heat of fusion
Aluminum....	625.0	158.3	258.3	100.0
Alumina....	2200.0	882.0	933.0	51.0
Antimony..	632.0	34.1	74.3	40.2
Bismuth....	267.0	9.0	21.0	12.0
Cadmium....	321.7	18.81	31.83	13.02
Copper.....	1085.0	117.0	162.0	45.0
Gold .....	.....	34.63	50.93	16.3
Iron .....	1450.0	300.0	369.0	69.0
Lead .....	326.0	11.6	15.6	4.0
Palladium....	962.0	64.8	89.15	24.35
Platinum....	1775.0°	75.2	102.4	27.2
Tin .....	.....	14.34	28.16	13.82
Zinc.....	420.0	45.2	67.8	22.6

<sup>1</sup> J. W. RICHARDS, "Metallurgical Calculations."

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## TOTAL HEAT CONTAINED IN CERTAIN SILICATES WHEN MELTED<sup>1</sup>

		Melting point	Heat in solid	Heat in liquid	Latent heat of fusion
Magnesium silicate (olivine).....	Mg <sub>2</sub> SiO <sub>4</sub>	1400°	520	650	130
Magnesium silicate (enstatite).....	MgSiO <sub>3</sub>	1300°	403	528	125
Potass.-alum. silicate (microcline)...	KAlSi <sub>3</sub> O <sub>8</sub>	1170°	.....	.....	83
Potass.-alum. silicate (orthoclase)...	KAlSi <sub>3</sub> O <sub>8</sub>	1200°	.....	.....	100
Calc.-alum. silicate (anorthite)....	CaAl <sub>2</sub> Si <sub>2</sub> O <sub>8</sub>	1220°	358	458	100
Calcium silicate (wollastonite).....	CaSiO <sub>3</sub>	1250°	360	460	100
Calc.-magnes. silicate (malacolite)...	Ca <sub>2</sub> MgSi <sub>2</sub> O <sub>7</sub>	1200°	319	413	94
Calc.-magnes. silicate (diopside)....	CaMgSi <sub>2</sub> O <sub>6</sub>	1225°	344	444	100
Iron silicate (fayalite).....	Fe <sub>2</sub> SiO <sub>4</sub>	1040°	310	395	85
Iron-alum. silicate (garnet).....	Fe <sub>3</sub> Al <sub>2</sub> Si <sub>3</sub> O <sub>12</sub>	1145°	.....	.....	.....

<sup>1</sup> The table is compiled from RICHARD'S "Metallurgical Calculations."

In general, the specific heat of a slag (silicate) may be calculated as the mean of the specific heat of the constituents, but a quick approximation is to take it at any temperature as being.

$$S_0(1 + 0.00078t)$$

and over any range of temperature as being

$$S_1(1 + 0.00039[t_1 - t_2])$$

where  $S_0$  is specific heat at 0° and  $S_1$  is specific heat at  $t_1$ .

## SOLUBILITY OF SALTS AT 10°C. AND BOILING<sup>1</sup>

One part requires for solution	Cold water	Hot water
Aluminum sulphate (+18H <sub>2</sub> O)	1.052	0.088
Ammonium alum (+12H <sub>2</sub> O)...	10.92	0.24
Ammonium carbonate.....	4.0	1.5
Ammonium chloride.....	3.04	1.37
Ammonium chlorplatinate....	150.0	80.0
Ammonium nitrate.....	0.54	0.19
Ammonium oxalate.....	22.22	2.45
Ammonium sulphate.....	1.358	1.026
Barium chloride (+2H <sub>2</sub> O)...	3.00	1.66
Barium hydrate (+8Aq).....	21.32	0.02
Barium nitrate.....	12.50	3.11
Boric acid.....	51.3(0°)	2.94
Bromine.....	30.0	31.9(30°)
Cadmium chloride.....	1.08	0.75
Calcium carbonate.....	Insoluble	.....
Calcium chloride (fused)	1.667	0.649
Calcium hydroxide.....	600.0	.....
Calcium nitrate.....	1.07(0°)	0.28(152°)
Calcium oxide.....	750.0	1500.0
Calcium sulphate (+2H <sub>2</sub> O)...	3.86(18°)	451.0
Chromic acid (CrO <sub>3</sub> ).....	0.607	.....
Chromic sulphate (+18H <sub>2</sub> O)...	0.833(20°)	.....
Cobaltous sulphate (+5H <sub>2</sub> O)...	2.9(20°)	.....
Copper sulphate (+5H <sub>2</sub> O).....	2.7	0.49

<sup>1</sup> CREMER and BICKNELL'S "Chemical and Metallurgical Handbook." For other tables of solubility see the table of "Properties of Compounds," p. 262, and "Properties of Precipitates," p. 420.

SOLUBILITY OF SALTS AT 10°C. AND BOILING. *Continued*

One part requires for solution	Cold water	Hot water
Copper acetate.....	14.28	5.05
Copper nitrate.....	0.78	.....
Ferrous chloride (+4H <sub>2</sub> O).....	0.68	.....
Ferric chloride.....	0.63	0.18
Ferrous sulphate (+7H <sub>2</sub> O).....	1.64	0.27
Lead acetate (+3H <sub>2</sub> O).....	1.00(40°)	0.5
Lead chloride.....	105.0	20.0
Lead nitrate.....	2.07	0.72
Lead sulphate.....	12,500	.....
Lithium chloride.....	1.24	0.7
Magnesium carbonate (+3H <sub>2</sub> O).....	552(16°)	.....
Magnesium chloride (+6H <sub>2</sub> O).....	0.6	0.27
Magnesium oxide.....	50,000	.....
Magnesium sulphate crystals.....	3.17	1.25
Manganous chloride.....	1.61	0.81
Manganous sulphate (+4H <sub>2</sub> O).....	0.79	1.07
Mercuric chloride.....	15.22	1.85
Oxalic acid.....	8.69	1.00
Potassium bitartrate.....	244.0	16.4
Potassium alum (+12H <sub>2</sub> O).....	10.50	0.28
Potassium bicarbonate.....	3.0	.....
Potassium bichromate.....	10.0	1.06
Potassium bromide.....	1.76	0.98
Potassium carbonate.....	0.91	0.64
Potassium chlorplatinate.....	89.3(20°)	19.3
Potassium chlorate.....	16.58	1.66
Potassium chloride.....	3.13	1.77
Potassium chromate.....	1.64	1.22
Potassium cyanide.....	0.82	.....
Potassium ferricyanide.....	2.73	1.29
Potassium ferrocyanide.....	3.4(15°)	1.1
Potassium hydrate.....	0.50	.....
Potassium iodide.....	0.7(20°)	0.5
Potassium nitrate.....	4.74	0.4
Potassium oxalate (acid).....	40.0	10.0
Potassium permanganate.....	16.0(15°)	.....
Potassium sulphate.....	10.31	3.82
Potassium sulphite.....	1.00	.....
Potassium bitartrate.....	250.0	9.52
Silver nitrate.....	0.4(19°)	0.09
Sodium acetate (+3H <sub>2</sub> O).....	4.0(6°)	1.7(48°)
Sodium bicarbonate.....	10.0	.....
Sodium bisulphate.....	3.5	.....
Sodium borate.....	21.3	1.82
Sodium bromide.....	1.13	0.87
Sodium carbonate (+10H <sub>2</sub> O).....	1.61	0.4(30°)
Sodium chlorate.....	1.0(20°)	0.49
Sodium chloride.....	2.78	2.53
Sodium hydrate.....	1.64	.....
Sodium hyposulphite (+5H <sub>2</sub> O).....	0.6	.....
Sodium nitrate.....	1.14(20°)	0.56
Sodium acid phosphate (Na <sub>2</sub> HPO <sub>4</sub> ·12H <sub>2</sub> O).....	6.7(15°)	0.4
Sodium sulphate (+10H <sub>2</sub> O).....	4.34	0.32(33)
Sodium sulphite.....	4.00	1.00
Strontium chloride.....	2.07	0.98
Strontium hydrate (+8H <sub>2</sub> O).....	55.5(20°)	2.1
Strontium nitrate.....	1.82	0.99
Stannous chloride.....	0.37	.....
Tartaric acid.....	1.31	0.50
Zinc chloride (+2H <sub>2</sub> O).....	0.25(15°)	.....
Zinc sulphate (+7H <sub>2</sub> O).....	0.72	0.15

## Solubilities of Solids in Water

$S$  = number of grams of anhydrous substance which when dissolved in 100 grams of water make a saturated solution at the temperature stated.

$p$  = number of grams of anhydrous substance per 100 grams of saturated solution.

Substance	0°C.	10	15	20	40	60	80	100
Am. chlor., $\text{NH}_4\text{Cl}$ , $S$ ...	29.4	33.3	35.2	37.2	45.8	55.2	65.6	77.3
Barium chlor., $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ , $S$ .....	31.6	33.3	34.5	35.7	40.7	46.4	52.4	58.8
Barium hydrate, $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ , $S$ ...	1.67	2.48	3.23	3.89	8.22	20.94	101.4	.....
Bromine (liquid), <sup>1</sup> $\text{Br}$ , $S$	4.17	3.74	3.65	3.58	3.45	.....	.....	.....
Cadmium sulphate, $\text{CdSO}_4 \cdot \frac{3}{2}\text{H}_2\text{O}$ , $S$ .....	76.5	76.0	76.3	76.6	78.5	83.7	70.2 <sup>2</sup>	60.77 <sup>3</sup>
Calcium hydrate, $\text{Ca}(\text{OH})_2$ , $S$ .....	0.185	0.176	0.170	0.165	0.141	0.116	0.094	0.077
Copper sulphate, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ , $S$ .....	14.3	17.4	18.8	20.7	28.5	40.0	55.0	75.0
Lithium carbonate, $\text{Li}_2\text{CO}_3$ , $S$ .....	1.54	1.43	1.38	1.33	1.17	1.01	0.850	0.720
Mercuric chloride, $\text{HgCl}_2$ , $p$ .....	3.50	4.50	5.00	5.40	9.30	14.0	23.1	38.0
Potass. chloride, $\text{KCl}$ , $S$	27.6	31.0	32.4	34.0	40.0	45.5	51.1	56.7
Potass. bromide, $\text{KBr}$ , $S$	53.5	59.5	62.5	65.2	75.5	85.5	95.0	104.0
Potass. iodide, $\text{KI}$ , $S$ ...	127.5	136.0	140.0	144.0	160.0	176.0	192.0	208.0
Potass. hydrate, $\text{KOH} \cdot 2\text{H}_2\text{O}$ , $S$ .....	97.0	103.0	107.0	112.0	138.0 <sup>3</sup>	.....	.....	178.0 <sup>3</sup>
Potass. nitrate, $\text{KNO}_3$ , $S$	13.3	20.9	25.8	32.0	64.0	110.0	169.0	246.0
Silver nitrate, $\text{AgNO}_3$ , $S$	122.0	170.0	196.0	222.0	376.0	525.0	669.0	952.0
Sodium carbonate, $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ , $S$ ...	7.0	12.5	16.4	21.5	46.1 <sup>4</sup>	46.0 <sup>4</sup>	45.8 <sup>4</sup>	45.5 <sup>4</sup>
Sodium chloride, $\text{NaCl}$ , $S$ .....	35.7	35.8	35.9	36.0	36.6	37.3	38.4	39.7
Sodium sulphate $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ , $S$ ...	5.0	9.0	13.4	19.4	49.0 <sup>5</sup>	45.0 <sup>5</sup>	44.0 <sup>5</sup>	42.0 <sup>5</sup>
Strontium chloride, $\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$ , $S$ .....	43.0	48.0	50.0	53.0	65.0	82.0	91.0 <sup>6</sup>	101.0 <sup>6</sup>

<sup>1</sup> Very soluble in ammonium-acetate solution.

<sup>2</sup> Solid phase becomes  $\text{CdSO}_4 \cdot \text{H}_2\text{O}$  at 74°.

<sup>3</sup> Becomes  $\text{KOH} \cdot \frac{3}{2}\text{H}_2\text{O}$  at 32.5° and  $\text{KOH} \cdot \text{H}_2\text{O}$  at 50°.

<sup>4</sup> Becomes  $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$  at 35°.

<sup>5</sup> Becomes  $\text{Na}_2\text{SO}_4$  at 32.38°.

<sup>6</sup> Becomes  $\text{SrCl}_2 \cdot 2\text{H}_2\text{O}$  at 70°.

The above formulas are those of the solid phases that are in equilibrium with the solution. The figures are from SEIDELL'S "Solubilities of Inorganic and Organic Substances." D. Van Nostrand & Co., New York.

## Solvents for Metals

Aluminum	HCl, HNO <sub>3</sub> , H <sub>2</sub> SO <sub>4</sub> , alkalis.
Antimony	Aqua regia, HNO <sub>3</sub> to oxide.
Arsenic	Aqua regia, HNO <sub>3</sub> to oxide.
Bismuth	HNO <sub>3</sub> .
Cadmium	HNO <sub>3</sub> .
Cobalt	HNO <sub>3</sub> .
Copper	HNO <sub>3</sub> .
Gold	Aqua regia.
Iron	HCl, dilute H <sub>2</sub> SO <sub>4</sub> , not by conc.
Lead	HNO <sub>3</sub> , boiling concn. H <sub>2</sub> SO <sub>4</sub> slightly.
Manganese	HCl.
Mercury	HNO <sub>3</sub> , boiling H <sub>2</sub> SO <sub>4</sub> .
Nickel	HNO <sub>3</sub> .
Platinum	Aqua regia.
Silver	HNO <sub>3</sub> , boiling H <sub>2</sub> SO <sub>4</sub> .
Tantalum	HF and HNO <sub>3</sub> mixed.
Tin	HCl, HNO <sub>3</sub> to oxide.
Tungsten	HNO <sub>3</sub> containing HF; fused KNO <sub>2</sub> .
Zinc	HCl, HNO <sub>3</sub> , H <sub>2</sub> SO <sub>4</sub> , alkalis.

In Dilute Solution (Fifth Normal or More Dilute)<sup>1</sup>

1. Copper is acted upon by cold dilute hydrochloric acid to a much greater extent than by sulphuric or nitric acids. Each of the last-named acids attacks the metal to about the same extent.

2. Aluminum is slowly attacked by dilute nitric acid and sulphuric acid.

3. Lead is more rapidly attacked by hydrochloric acid than by sulphuric acid, the action of the latter acid being negligible.

4. Tin is soluble in caustic soda and in sodium carbonate solution, but not in ammonia.

**Action of Acetylene upon Metals** (*Chem. Zeit.*, 1915, 89, 42).

—In acetylene installations explosions have sometimes occurred which have been attributed to the formation of explosive compounds of acetylene with the metal of the fittings. In a series of experiments it was found that pure dry acetylene in contact for 20 months with the following metals had no action upon them: zinc, tin, lead, iron, copper, nickel, brass, German silver, phosphor bronze, aluminum bronze, type metal, solder. With pure moist acetylene nickel and copper were both attacked. Unpurified moist gas, as obtained in the ordinary way from commercial carbide, had no appreciable action on tin, German silver, aluminum bronze, type metal or solder, but had a distinct action on zinc, lead, brass, much more on iron and bronze, and still more on phosphor bronze, while the action on copper was very rapid; but it is stated that in no case were explosive substances produced. It is recommended that metal fittings used in connection with acetylene should be coated with nickel or tin.

<sup>1</sup> A. J. HALE and H. S. FOSTER, *Journ. Soc. Chem. Ind.*, May 15, 1915.

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### SOLUBILITY OF METALS IN ACIDS<sup>1</sup>

(24 Hours Immersion at 15 Deg. C. Loss Per Sq. Cm. of Surface in Grams)

Metal	Conc. HCl	H <sub>2</sub> SO <sub>4</sub> 10% by vol.	HNO <sub>3</sub> sp. gr. 1.20 50% by vol.
Iron.....	0.0814	0.0327	0.7165
Nickel.....	0.0037	0.0002	0.1546
Chromium.....	0.2014	0.0014	0.0006
Copper.....	0.0018	0.0002	0.5708
Cobalt.....	0.0480	0.0150	0.4210
Manganese.....	0.1579	0.7724	0.5688
Aluminum.....	0.1071	0.0002	0.0010
Silicon.....	0.0002	0.0003	0.0002
Molybdenum.....	0.000002	0.0001	0.0096

<sup>1</sup> *Chem. and Met. Eng.*, Oct. 6, 1924.

### ACTION OF SULPHUR MONOCHLORIDE ON CERTAIN PURE METALS<sup>1</sup>

Metal	Form	Per cent loss in weight after 52 weeks	Remarks
Aluminum .	Foil	100	Dissolved immediately with great evolution of heat
Antimony...	Lump	100	Dissolved immediately with considerable heat
Arsenic.....	Lump	85.6	
Bismuth . .	Lump	2.1	
Cadmium ....	Stick	0.4	
Chromium . .	Lump	0.0	
Cobalt. ....	Lump	0.0	
Copper.	Foil	33.5	The scale which quickly forms protects the metal beneath
Lead.....	Foil	( <sup>3</sup> )	
Nickel.....	Foil	0.14	
Manganese...	Lump	100	Dissolved after several days
Silver.....	Foil	( <sup>4</sup> )	
Tin.....	Foil	4.0	A brown sticky film protects the metal beneath
Zinc.....	Stick	5.7	

(<sup>3</sup>) Increased in weight 1.3 per cent.

(<sup>4</sup>) Increased in weight 0.4 per cent.

<sup>1</sup> Prepared by Ellery H. Harvey, of Montgomery, Ward & Co., Chicago.

III.

### Corrosion Due to H<sub>2</sub>S<sup>1</sup>

The following table shows the corrosion of strips of metal in the upper portion of a cracking still running on a stock containing 0.25 to 0.30% S at a temperature of 735°F.

<sup>1</sup> Wilson and Bahlke, *Journ. Ind. Eng. Chem.*, Vol. 17, 1925, p. 357.



Metal	Loss mg./sq. cm. per run	Number of runs
Aluminum.....	None	60
Calite casting.....	None	60
Calorized plate.....	None	50
Duralumin.....	None	10
Stainless steel (Firth-Sterling).....	0.03	33
Ascoloy.....	0.03	94
Aluminum bronze.....	0.11	38
Galvanized iron.....	0.55	50
Zinc.....	0.60	10
Cast iron.....	2.73	30
Vismery steel.....	2.96	10
Special Climax alloy steel.....	3.32	33
Still-bottom steel.....	3.44	30
Copper-bearing steel.....	3.49	10
Low chromium alloy steel.....	3.68	20
Wrought iron.....	3.69	10
Monel.....	3.85	10
Bronze.....	19.25	10
Brass.....	21.80	10
Copper.....	40.60	10

### Reaction of Sulphur Chloride with Metals<sup>1</sup>

Previous investigators have shown that some metals do not react with sulphur chloride either in the cold or on heating, while others react only on heating, and in a few cases the reaction begins at the ordinary temperature; the products of the reaction are sulphur and chlorides of the metals, with small proportions of sulphur compounds. The author finds that the reaction may be brought about or greatly accelerated by the agency of dry ether, with which the metallic chlorides form complexes and so enhance the thermal effect of the reaction. Under these conditions, magnesium, zinc, aluminum, tin, antimony, bismuth, molybdenum, iron, mercury, and gold are readily converted into their chlorides or etherates of the latter. On the other hand, the alkali metals, calcium, cadmium, thallium, lead, tungsten, chromium, manganese, cobalt, nickel, copper, silver, and platinum, react either not at all or with extreme slowness. The metals which do react either (1) give chlorides which readily form etherates, as is the case with zinc, aluminum, tin, and bismuth, or (2) give chlorides which are readily fusible and volatile and approximate in their properties to the chloro-anhydrides; in correspondence with the latter, the higher chlorides are mostly formed, for instance,  $\text{ZnCl}_4$ ,  $\text{FeCl}_3$ ,  $\text{HgCl}_2$ . Univalent metals do not react and divalent metals—excepting mercury—if at all, react with far greater difficulty than trivalent and quadrivalent metals. It is probable that other metals, giving volatile higher chlorides, such as titanium, germanium, vanadium,

<sup>1</sup> N. DOMANICKI, *Journ. Russian Phys. Chem. Soc.*, 1916, Vol. 48, p. 1724.

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and the like, would also react readily with sulphur chloride and ether.

### Solubility of Air in Water<sup>1</sup>

1000 cc. of water saturated with air at 760 mm. pressure contain the following volumes of dissolved gas (calculated to volume at 0°C. and 760 mm.).

	Temperature of water						
	0°	5°	10°	15°	20°	25°	30°
Oxygen, cc. ....	10.19	8.9	7.9	7.0	6.4	5.8	5.3
Nitrogen, argon, etc. ....	19.0	16.8	15.0	13.5	12.3	11.3	10.4
Sum of above, cc. ....	29.2	25.7	22.8	20.5	18.7	17.1	15.7
Per cent. oxygen in dissolved air (by volume) ..	34.9	34.7	34.5	34.2	34.0	33.8	33.6

### SOLUBILITY OF SULPHUR DIOXIDE IN WATER (760 mm. pressure<sup>2</sup>)

Temperature of water, deg. C.	20	30	40	50	60	70	80	90	100
SO <sub>2</sub> , per cent. dissolved	8.6	7.4	6.1	4.9	3.7	2.6	1.7	0.9	0.0

### SOLUBILITY OF GASES IN WATER (760 mm. pressure<sup>3</sup>)

	Volumes, 0°C.	Volumes, 15°C.	Volumes, 30°C.	Volumes, 60°C.
Oxygen .....	0.0489	0.03415	0.02608	0.019
Nitrogen .....	0.02388	0.01686	0.01380	0.0100
Carbon monoxide .....	0.03537	0.02543	0.01998	0.015
Carbon dioxide .....	1.713	1.019	0.665	0.36
Ammonia .....	1300.0	802.0	598.0	.....
Argon .....	0.058	0.041	0.030	.....
Chlorine .....	.....	2.63	1.77	1.0
Helium .....	0.0150	0.0139	0.0138	.....
Hydrogen .....	0.0215	0.0188	0.018	.....
Hydrochloric acid .....	506.0	458.0	411.0	339.0
Nitrous oxide .....	.....	0.74	0.63	.....
Nitric oxide .....	0.074	0.0515	0.040	0.029
Sulphuretted hydrogen .....	4.68	3.05	2.67	.....
Sulphur dioxide .....	79.8	47.3	27.2	18.8
Acetylene .....	.....	1.15	.....	40°
Hydrobromic acid .....	.....	581.0	.....	.....
Air .....	.....	0.02045	.....	.....
Bromine .....	.....	28.4	.....	.....

<sup>1</sup>In the majority of the above cases the gases are in equilibrium with the water at 760° mm. pressure.

<sup>2</sup>KAYE and LABY'S "Chemical and Physical Constants."

<sup>3</sup>HOFMAN'S "General Metallurgy."

<sup>4</sup>Compiled from various authorities.

SHRINKAGE OF METALS<sup>1</sup>

Metal	Casting temperature, deg. C.	Freezing point, deg. C.	Shrinkage during freezing, per cent. of volume	Total shrinkage, per cent. of volume
Pb...	500	326	0.065	0.82
Pb...	600	326	0.065	0.83
Zn.	650	416	0.08	1.40
Zn.	700	416	0.08	1.40
Zn.	750	416	0.08	1.40
Sn (Banca)	550	225	0.1-0.15	0.44
Sn	500	225	0.1-0.15	0.55
Al	800	683	6.6	8.2
Al.	700	683	6.6	7.2
Cu	1250	1060	Expansion	1.42
Bi.	500	261		0.29
Sb	710	621		0.29
Sb	750	621		0.63
Sb	800	621		0.29
Sb.....	1050	621		0.66
Na <sup>2</sup> ...	..	...	...	2.57

<sup>1</sup> From HOFMAN'S "General Metallurgy," originally from Wüst, *Metal-lurgie*, Vol. 6, 1909, p. 769.

<sup>2</sup> *Chem. Trade Journ.*, June 26, 1915.

The expansion of copper is to be attributed to the setting free of dissolved gas. The lead, zinc, copper and antimony that Wüst worked with were not even commercially pure. This may account for the inconsistency of his results with those of other authorities, given below.

SHRINKAGE OF METALS<sup>1</sup>

Metals	Percentage increase of volume on melting
Sodium.....	2.5 (a)
	2.5 (b)
Potassium . . . . .	2.5 (a)
	2.6 (b)
Tin . . . . .	2.8 (a)
	2.8 (c)
Cadmium.....	5.2 (a)
	4.72 (c)
Lead . . . . .	2.7 (a)
	3.39 (c)
Thallium . . . . .	3.1 (a)
Zinc . . . . .	0.9 (a)
Aluminum . . . . .	6.6 (e)
Tellurium.....	7.3 (a)
Antimony.....	1.4 (a)
Bismuth. . . . .	-3.27 (a)
	-3.31 (c)
	-3.0 (d)

(a) M. TOEPLER, *Annalen der Physik*, 1888, Vol. 34, p. 21.

(b) H. BLOCK, *Zeit. für Phys. Chem.*, 1912, Vol. 78, p. 385.

(c) G. VINCENTINI and D. OMODEI, *Atti R. Accademia delle Scienze di Torino*, 1889, Vol. 31, p. 25.

(d) C. LUDKING, *Annalen der Physik*, 1888, Vol. 34, p. 21.

(e) Recent work by Aluminum Co. of America.

<sup>1</sup> Compilation in *Engineering*, Apr. 3, 1914, p. 473.

## THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)		
						Water, 20°C.	Hot water	Absolute alcohol, cold
Aluminum	Al	27.1	2.70	660	1800	i	i	i
Bromide	AlBr <sub>3</sub>	266.71	3.01	97.5	265	s	s	i cold dil. H <sub>2</sub> SO <sub>4</sub> , NaOH, KOH, HNO <sub>3</sub> , HCl
Chloride	AlCl <sub>3</sub>	133.33	2.44	194		70:100	s	1:2
Fluoride	AlF <sub>3</sub>	83.96	3.1	1040		i	i	s
Hydroxide	Al(OH) <sub>3</sub>	77.98	2.3	Dec		i	i	s
Iodide	AlI <sub>3</sub>	407.76	3.98	191	360	s	s	s-CS <sub>2</sub>
Nitrate	Al <sub>2</sub> (NO <sub>3</sub> ) <sub>3</sub> ·9H <sub>2</sub> O	375.12	73	Dec. 134		v.s	s	s
Oxide	Al <sub>2</sub> O <sub>3</sub>	101.92	3.68	2050		i	i	1
Phosphate	AlPO <sub>4</sub>	121.98	2.59			i	i	s conc. acids
Sulphate	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	342.11	2.71	Dec 770		36:100	89:100	1
Sulphide	Al <sub>2</sub> S <sub>3</sub>	150.11	2.02	1100		Dec.	595 at 28°	12:100
Ammonia	NH <sub>3</sub>	17.03	liq. 817	-77.7	-33.5	710:1 vols		
Ammonium:								
Acetate	NH <sub>4</sub> C <sub>2</sub> H <sub>3</sub> O <sub>2</sub>	77.06	1.073	114		14.8:100	s	s
Alum.	NH <sub>4</sub> Al(SO <sub>4</sub> ) <sub>2</sub> ·12H <sub>2</sub> O	453.47	1.63			9:100	s	i
Arsenate	(NH <sub>4</sub> ) <sub>2</sub> AsO <sub>4</sub> ·3H <sub>2</sub> O	247.1				s	s	
Brominate	(NH <sub>4</sub> ) <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	252.08				v.s.	v.s.	
Bromide	NH <sub>4</sub> Br	97.95	2.55	137.4		74:100	128:100	3.06:100
Carbonate	(NH <sub>4</sub> ) <sub>2</sub> CO <sub>3</sub>	96.08		Dec		72:100	v.s.	1 s
Chloride	NH <sub>4</sub> Cl	53.50	1.54	Sublimes		37:100	87:100	0.62:100
Chlorplatinate	(NH <sub>4</sub> ) <sub>2</sub> PtCl <sub>6</sub>	444.06		Dec.		0.67:100	1:80	1
Chromate	(NH <sub>4</sub> ) <sub>2</sub> CrO <sub>4</sub>	136.08	3.06	Dec.		Dec.	Dec.	v.s.
Fluoride	NH <sub>4</sub> F	37.04	1.88	Dec.		v.s.	v.s.	1 s
Hydroxide	NH <sub>4</sub> OH	35.05		Solut. -40		v.s.	v.s.	v.s.
Iodide	NH <sub>4</sub> I	144.97	2.56	-17		v.s.	v.s.	v.s.

Ammonium:	$\text{NH}_4\text{MgAsO}_4 \cdot \text{H}_2\text{O}$	198.33	Dec.	.....	0 02.100	i	i	s
Magnes. arsenate	$\text{NH}_4\text{Mg}_2\text{PO}_4 \cdot 6\text{H}_2\text{O}$	245.52	Dec.	.....	0 005:100	i	i	s
Magnes. phosph.	$(\text{NH}_4)_2\text{MoO}_4 \cdot 4\text{H}_2\text{O}$	1236.32	Dec.	.....	Dec.	Dec.	i	s
Molybdate			2.4-2.9					
Nitrate.....	$\text{NH}_4\text{NO}_3$	80.05	169 6	210 Dec.	200:100	1:1	1:2	v.s.
Nitrite.....	$(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$	64.05	Dec.	.....	192:100	v.s.	3.8:100	
Oxalate.....	$(\text{NH}_4)_2\text{HPO}_4$	142.1	1.5	.....	1:4	s	i	
Phosphate.....	$(\text{NH}_4)_2\text{PO}_4 \cdot 10\text{MoO}_3$	132.13	1.5	.....	1:4	s	i	
Phospho. molyb.	$\text{O}_3 \cdot 3\text{H}_2\text{O}$	1644.26	.....	.....	0 03:100	i	i	i-HNO <sub>3</sub>
Platin. chlor.....	$(\text{NH}_4)_2\text{PtCl}_6$	444.06	Dec.	.....	1:150	1:80	0 005:100	s
Sulphate.....	$(\text{NH}_4)_2\text{SO}_4$	132.15	1.77	Sublimes	75:100	107:100	1.s.	
Sulphhydrate.....	$\text{NH}_4\text{HS}$	51.12	140	.....	s	s	s	s-aq. reg. i-HCl
Sulphocyanate.....	$\text{NH}_4\text{SCN}$	76.12	120	.....	162:100	v.s.	s	
Antimony.....	Sb	130.2	6.68	1380	.....	.....	.....	
Bromide.....	$\text{SbBr}_3$	361.52	4 15	280	Dec	Dec.	Dec.	v.s. HCl
Chloride.....	$\text{SbCl}_3$	289.06	liq. 2.34	102 5	Dec	Dec.	Dec.	v.s. $\text{CH}_3\text{I}_2$
Hydride.....	$\text{SbH}_3$	124.79	4 77	-88	20:100	vols.	.....	s-HCl
Iodide.....	$\text{SbI}_3$	502.56	4 85	167	Dec.	Dec.	Dec.	s-HCl
Ous chloride.....	$\text{SbCl}_3$	228.14	2.67	401	Dec.	Dec.	Dec.	s-NH <sub>4</sub> HS
Ous oxide.....	$\text{Sb}_2\text{O}_3$	291.54	5.2-5.7	223	Dec.	Dec.	Dec.	s-NH <sub>4</sub> HS
Ous sulphide.....	$\text{Sb}_2\text{S}_3$	339.74	4.64	Sublimes	.....	.....	.....	s-NH <sub>4</sub> HS
Oxide.....	$\text{Sb}_2\text{O}_3$	323.51	3.8	550	.....	.....	.....	s-HCl
Sulphide.....	$\text{Sb}_2\text{S}_3$	400.75	.....	Dec.	.....	.....	.....	s-HCl
Trichloride.....	$\text{SbCl}_3$	228.58	Red heat	.....	.....	.....	.....	
Oxy chloride.....	$\text{SbOCl}$	173.23	73 2	.....	816:100	.....	.....	
Oxy sulphate.....	$(\text{SbO})_2\text{SO}_4$	368.47	Dec.	at 170	i	Dec.	Dec.	
Arsenic:			.....	.....	.....	.....	.....	
Arsenoph.	As	74.96	4.71	Sublimes	i	i	i	
Cryst.....	As	74.96	5.75	130	i	i	i	
Oxide.....	$\text{As}_2\text{O}_3$	229.92	814	.....	i	i	i	
Sulphide.....	$\text{As}_2\text{S}_3$	310.27	(36 atm.)	.....	245:100	.....	.....	s-alkalies
Arsenous:			Red heat	Dec. Sublimes	.....	.....	.....	
Bromide.....	$\text{AsBr}_3$	314.71	3.54	220	Dec.	Dec.	Dec.	s-HCl
Chloride.....	$\text{AsCl}_3$	181.34	2.16	132	Dec.	Dec.	Dec.	s-HCl

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)		
						Water, 20°C.	Hot water	Absolute alcohol, cold
<b>Arsenic:</b>								
Fluoride	AsF <sub>3</sub>	131.96	2.67	-80	63	Dec.	Dec.	
Iodide	AsI <sub>3</sub>	455.72	4.39	146	404	Dec.	Dec.	0 45:100
Oxide	As <sub>2</sub> O <sub>3</sub>	197.92	3 7-3 74	275		3 7-100	1:10	
Realgar	As <sub>2</sub> S <sub>2</sub>	214.06	3.5	267		1	1	
Sulphide	As <sub>2</sub> S <sub>3</sub>	246.13	3.48	170		1	1	
Arsine	AsH <sub>3</sub>	77.98	3.48	-113.5	-54.8	1 s	1	
<b>Auric:</b>								
Bromide	AuBr <sub>3</sub>	436.95		Dec 160		s	s	
Chloride	AuCl <sub>3</sub>	303.57		Dec 254		6 s, 100:	s	s
Cyanide	Au(CN) <sub>3</sub> ·3H <sub>2</sub> O	329.27	3.9	Dec 50		v s	v s	
Hydroxide	Au(OH) <sub>3</sub>	248.22		Dec.		1	1	
Iodide	AuI <sub>3</sub>	577.96		Dec.		1	1	
Oxide	Au <sub>2</sub> O <sub>3</sub>	442.4		Dec 160		1	1	
Sulphide	Au <sub>2</sub> S <sub>3</sub>	490.60		Dec. 197		1	1	
<b>Aurous:</b>								
Chloride	AuCl	232.66	7.4	Dec. at 290		Dec	Dec.	
Cyanide	AuCN	223.21		Dec.		1	1	1
Iodide	AuI	324.13		Dec. 120		1	1	
Oxide	Au <sub>2</sub> O	410.4		Dec. 203		1	1	
Sulphide	Au <sub>2</sub> S <sub>2</sub>	458.53		Dec. 140		1	1	
Barium	Ba	137.37	3.5	850	1140	Dec	Dec	
Bromide	BaBr <sub>2</sub> ·2H <sub>2</sub> O	333.23	3.85	847		1 1	149:100	3:100
Carbonate	BaCO <sub>3</sub>	197.37	4.3	Dec begins 1361		0 02:1000	1	1
Chlorate	Ba(ClO <sub>3</sub> ) <sub>2</sub>	304.29		4 14		1:4	1:0 80	1
Chloride	BaCl <sub>2</sub> ·2H <sub>2</sub> O	244.32	3.05	847		36, 100:	78:100	0.14:100
Chromate	BaCrO <sub>4</sub>	253.38	4.50			0 003:1000	0.043:1000	
Hydrate	Ba(OH) <sub>2</sub> ·8H <sub>2</sub> O	315.51	2.13	77 9 Dec		3.89:100	1:1	1 s

Barium.	391.23	5 15	740 dec.	203.100	295.100 84.100	1:100	l.s. s-HCl s
Iodide.	261.39	3 24	592	1.12	s	i	
Nitrate.	153.37	5 72	1923	i	Dec.		
Oxide.	169.37	4 96	Red heat	i	i		
Peroxide	602.16	4 12					
Phosphate							
Pyrophos.	448.79	4 12					
Silicofluoride	279.43	4 28	Dec.	i	i		
Sulphate	233.44	4 5	1580	0.002.1000	i		l.s. in HCl s
Sulphide	169.44	4.25		Dec.	s		
Sulphydrate	203.53						
Beryllium							
Bromide	168.85	1 8	1350				
Chloride	79.94		490	1500			
BeSO <sub>4</sub> ·4H <sub>2</sub> O	177.15	1 7	Dec	Red heat			
Sulphate	208 0	9.8	271	44:100	85:100		
Bismuth.	448.75	5 7	218	Dec.			
Bromide	315.38	4.7	230	Dec. with excess			s-HNO <sub>3</sub> s-HCl s
Chloride.							
Hydroxide	259.02						
Iodide	589.80	5 7	>439	i	i	3.5:100	
Nitrate.	485.10	2 83	74	Dec.	Dec.		
Oxide	466.0	8.2-8.9	820	i	i		
Sulphate	704.21		Dec.	Dec.			
Sulphide.	514.20	7-7.8	264	i	i		
Boric.							
Acid.	61.84	1.48	185		27.5:100	1-6	
Anhydride.	69.64	1 85	577	1.25	16:100	s	
Bromide.	250.57	2 60	90	1.40			
Chloride	117.19	1.43	-104	Dec.	Dec.		
Fluoride	67.82		-107	1:1 by vol.	i		v.s.-H <sub>2</sub> SO <sub>4</sub>
Boron	10.82	2 00	2350			1	
Bromine	79.92	3.40	-7.2	3 5:100	s. to 60°		v.s.-KBr sol. s
Cadmium.	112.41	8.69	320.9				
Bromide.	272.24	4.7-4.9	583	49:100	61:100	1:6	
Carbonate	172.41	4.49	Dec < 500	0 003:1000	15:10 <sup>1</sup>	s	
Chloride.	183.33	4 07	588	14:10 <sup>1</sup>			

<sup>1</sup> The anhydrous salt is referred to.

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point deg. C.	Boiling point deg. C.	Solubility (parts solid to parts water)			
						Water, 20°C.	Hot water	Absolute alcohol, cold	Acids
<b>Cadmium:</b>									
Hydroxide.....	$\text{Cd}(\text{OH})_2$	146.42	4.79	Dec. 300	132	i	i	.....	s
Nitrate.....	$\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$	308.48	2.4	59.5	.....	127:100	vs	.....	.....
Oxide.....	$\text{CdO}$	128.41	8.15	.....	.....	i	.....	.....	.....
Sulphate.....	$\text{CdSO}_4 \cdot 7\text{H}_2\text{O}$	334.58	2.48	1000	.....	76.6:100	vs	.....	v.s. $\text{H}_2\text{SO}_4$ i-dil. s-conc. acids
Sulphide.....	$\text{CdS}$	144.47	4.69	1750	.....	i	i	.....	.....
<b>Cesium:</b>									
Carbonate.....	$\text{Cs}_2\text{CO}_3$	325.62	1.9	26	670	vs.	vs.	11:100	.....
Chloride.....	$\text{CsCl}$	168.27	3.97	646	.....	186:100	290:100	.....	.....
Hydride.....	$\text{CsH}$	133.82	2.7	Dec	.....	Dec.	.....	.....	.....
Hydroxide.....	$\text{CsOH}$	149.82	4.02	Red heat	.....	s	.....	.....	.....
Nitrate.....	$\text{CsNO}_3$	194.82	3.69	414	Dec.	23:100	220:100	.....	.....
Nitride.....	$\text{Cs}_3\text{N}$	40.07	1.58	810	1170	Dec.	Dec.	Dec.	Dec.
Bromide.....	$\text{CsBr}$	189.90	3.35	765	.....	143:100	312:100	Dec.	s
Carbonate.....	$\text{CaCO}_3$	100.07	2.7-2.9	Dec. 825	.....	0.012:1000	i	i	s
Chloride.....	$\text{CaCl}_2$	110.99	2.2	772	.....	72:100	35:10	s	s
Chloride of lime.....	$\text{CaOCl}_2$	126.99	.....	.....	.....	s	.....	.....	s
Fluoride.....	$\text{CaF}_2$	78.07	3.18	1360	.....	0.03:2000	.....	.....	s
Hydroxide.....	$\text{Ca}(\text{OH})_2$	74.09	2.34	Dec.	.....	0.17:100	0.08:100	i	s
Iodide.....	$\text{CaI}_2$	283.93	4.9	575	710	192:100	230:100	.....	.....
Nitrate.....	$\text{Ca}(\text{NO}_3)_2$	164.09	2.36	561	.....	54.8:100	.....	.....	.....
Oxide.....	$\text{CaO}$	56.07	3.4	2570	.....	0.13:100	0.06:100	i	s
Phosphate.....	$\text{Ca}_3(\text{PO}_4)_2$	310.26	3.18	1670	.....	0.003:100	i	.....	s
Sulphate.....	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	172.17	2.31	Dec.	.....	1:500	1:460	i	l.s.
Carbon.....	C	12.00	2.2-3.5	.....	.....	i	i	i	i
Tetrachloride.....	$\text{CCl}_4$	153.84	1.582	-23.8	76.7	.....	.....	.....	.....
Carbonic Acid.....	$\text{H}_2\text{CO}_3$	62.02	.....	.....	.....	s	s	.....	s



Carbonic:	CO <sub>2</sub>	44.00		-70		1:1 vol.		3:100 vol.	
Anhydride	CS <sub>2</sub>	76.14	1.29	-110	46.6	0.1:100		∞	
Disulphide	CO	26.00	6.74	-207	-190	1:30 vols		s	
Oxide	Cerium(II) oxide	172.25	6.90	640	1400				
Cerium(ous)	Ce	246.63	3.92	848					
Chloride	CeCl <sub>3</sub>	172.25	7.3	1950					
Oxide	Ce <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> ·8H <sub>2</sub> O	712.82	2.88	630		16 5:100		1:200	
Sulphate	Chloric acid	210.58	1.28	40	Dec.	v.s		1:1 4	
Chlorine	HClO <sub>4</sub> ·7H <sub>2</sub> O	35.46		-101.6	-34.6	1:2.5 vol			
Chromium	Cr	52.00	7.1	1615	2200				s-HCl, H <sub>2</sub> SO <sub>4</sub>
Chromic:	CrO <sub>3</sub>	100.01	2.70	Dec. 190	Dec.	165 5:100	v.s		
Anhydride	Cr <sub>2</sub> Cl <sub>6</sub>	316.76	2.70		Sublimes	1:1	s		
Chloride	Cr <sub>2</sub> (OH) <sub>6</sub>	206.04		Dec.	Dec		s		s-alk. acids
Hydroxide	Cr <sub>2</sub> O <sub>3</sub>	152.02	5.21	1900					
Oxide	Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> ·17H <sub>2</sub> O	698.48	1.70	Dec. 100		120:100	s		
Sulphate	Chrome:								
Alum	K <sub>2</sub> Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>4</sub> ·4H <sub>2</sub> O	998.82				1:8 <sup>1</sup>	s		
Green	Cr <sub>2</sub> O <sub>3</sub>	152.02	5.21	1900					
Orange	PbO·PbCrO <sub>4</sub>	546.20							
Yellow	PbCrO <sub>4</sub>	323.10	6.3	844					
Cobalt:	Co	58.97	8.95	1480	2900				
Cobaltic:	Co <sub>2</sub> Cl <sub>6</sub>	330.70	2.94	Dec.		s			s-HNO <sub>3</sub>
Chloride	Co <sub>2</sub> O <sub>3</sub>	165.94	5.18	Dec. at red heat		1			s-HNO <sub>3</sub>
Oxide									
Cobaltous:									
Chloride	CoCl <sub>2</sub>	129.89	3.36	Subl. 87		29 5:100	51:100	1:4	
Hydroxide	Co(OH) <sub>2</sub>	92.99	3.6	Dec.					
Oxide	CoO	74.97	5.7	Dec. 800					
Sulphate	CoSO <sub>4</sub> ·7H <sub>2</sub> O	281.14	1.95	96.8		36:100 <sup>1</sup>	83:100 <sup>1</sup>	1:50	
Columbium									
chloride	CbCl <sub>3</sub>	270.39	2.75	194	240.5	Dec.			
Copper	Cu	63.57	8 85-8.94	1083	2300				

<sup>1</sup> The anhydrous salt is referred to.

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)			
						Water, 20°C.	Hot water	Absolute alcohol, cold	Acids
Cupric: Acetate	$\text{Cu}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot \text{H}_2\text{O}$	199.64	..	Dec. at 240	..	1:131	2:10	1:14	s
Carbonate	$\text{CuCO}_3$	123.57	..	Dec	..	i	i	i	s
Chloride	$\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$	170.52	2.39	498	Dec. 500	7:10 <sup>1</sup>	103:100	s	s
Hydrate	$\text{Cu}(\text{OH})_2$	97.59	..	Dec.	..	i	i	s	s
Nitrate	$\text{Cu}(\text{NO}_3)_2$	187.59	2.17	114.5	170	5:4	v.s.	v.s.	s
Oxide	$\text{CuO}$	79.57	6.4	Dec 1026	..	i	75:100 <sup>1</sup>	i	s
Sulphate	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	249.72	2.27	Dec at red heat	..	1:5 <sup>1</sup>	..	i	s
Sulphide	$\text{CuS}$	95.64	4.6	1035	..	i	i	i	1-dil. ac.
Cuprous: Chloride	$\text{Cu}_2\text{Cl}_2$	198.06	3.5	422	1000	l.s.	..	..	s-HCl, $\text{NH}_4\text{OH}$ .
Oxide	$\text{Cu}_2\text{O}$	143.14	6.0	Dec 1235	..	i	i	..	s-NH <sub>4</sub> OH
Sulphide	$\text{Cu}_2\text{S}$	159.21	5.6	1100	..	..	i	..	s-HNO <sub>3</sub>
Cyanogen	$(\text{CN})_2$	52.02	Liq. 0.866	-34.4	-20.5	4.5:1 vol.	..	23:1	5:1 ether
Erbium: Nitrate	$\text{Er}_2(\text{SO}_4)_3 \cdot 8\text{H}_2\text{O}$	767.74	3.18	..	..	23:100	..	..	..
Oxide	$\text{Er}_2\text{O}_3$	383.4	8.6	..	..	i	i	..	..
Ferric: Acetate	$\text{Fe}_3(\text{C}_2\text{H}_3\text{O}_2)_4 \cdot \text{Aq.}$	664.39	1.7	Dec.	..	i	i	..	s
Ammon. sulphate	$\text{Fe}_2(\text{NH}_4)_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}$	964.39	..	..	..	1:3	v.s.	i	s
Bromide	$\text{FeBr}_2 \cdot 6\text{H}_2\text{O}$	403.68	..	27	Red heat	s	s	s	s
Chloride	$\text{FeCl}_3$	324.44	2.8	282	Dec. 290	91:100	v.s.	v.s.	s-HNO <sub>3</sub>
Disulphide	$\text{FeS}_2$	119.98	5.0	..	..	i	i	i	s
Ferrocyanide	$\text{Fe}_3(\text{FeC}_5\text{N}_6)_2$	859.06	..	Dec.	..	i	i	i	s
Hydroxide	$\text{Fe}(\text{OH})_3$	213.73	3.4-3.9	Dec.	..	i	i	i	s
Nitrate	$\text{Fe}_2(\text{NO}_3)_6 \cdot 18\text{H}_2\text{O}$	808.03	1.68	47.2	125	s	s	s	s

	375.68	4.9-5.3	Dec.	s	s	s-HCl s s s
Ferric Oxalate.... $\text{Fe}_2(\text{C}_2\text{O}_4)_3$	159.68	4.9-5.3	Dec 1560	i	i	s
Oxide..... $\text{Fe}_2\text{O}_3$	373.82			i	i	s
Phosphate.... $\text{Fe}_2(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$	562.03	2.0	112	26:100 <sup>1</sup>	Dec.	s
Sulphate..... $\text{Fe}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$						s
Ferrous: Ammon. sulphate.... $\text{Fe}(\text{NH}_4)_2(\text{SO}_4) \cdot 6\text{H}_2\text{O}$	392.15	1.81	Dec at redness,	22:100	52:100	s
Carbonate.... $\text{FeCO}_3$	115.84	3.8		i	i	s-H <sub>2</sub> CO <sub>3</sub> s l.s.
Chloride..... $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$	198.82	2.80	Sublimes	13:10	v.s.	s
Ferric oxide .. $\text{Fe}_2\text{O}_3$	231.52	5-5.4	Dec 1538	1 s.	i	s
Hydroxide .... $\text{Fe}(\text{OH})_3$	89.86		Dec.	45:100 <sup>1</sup>	62:100 <sup>1</sup>	s
Nitrate..... $\text{Fe}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	349.96	2.28	35	s	s	s
Oxalate..... $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$	179.87		Dec 160	26:100	33:10	s
Oxide..... $\text{FeO}$	71.84	1.88	1380	i	i	s
Sulphate..... $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	278.01	64	Dec.	26:100	33:10	s
Sulphide ..... $\text{FeS}$	87.91	4.8	1193	1	i	s
Fluorine .....	19.00		-223		*	s
Gadolinum sulphate $\text{Gd}_2(\text{SO}_4)_3$	602.71	4.14		2.3:100		
Gallium chloride. $\text{GaCl}_3$	140.64		175			
Gallium chloride $\text{GaCl}_3$	176.09		75.5			
Germanium... $\text{Ge}$			958			
Chloride..... $\text{GeCl}_4$	214.21	1.87	-49.5	Dec.	1.07:100	s-Aq. reg.
Oxide..... $\text{GeO}_2$	104.38	4.70		0.4:100		
Gold (see Aurum)	197.2	19.26-.55	1063	i	i	i
Graphite..... $\text{C}$	12.00	2.2	3500	i	i	i
Hydrodic acid.... $\text{HI}$	127.93	2.85	-50.8	v.s	s	s
Hydrobromic acid. $\text{HBr}$	80.93	2.16	-87	221:100	130:100	v.s. ether
Hydrochloric acid. $\text{HCl}$	36.47	1.27	-112.5	500:1 vol.	s	v.s.
Hydrocyanic acid.. $\text{HCN}$	27.02	0.697	-13.8	$\infty$	$\infty$	$\infty$
Hydrofluoric acid.. $\text{HF}$	20.02	0.988	-83	111:100	v.s.	
Hydrogen .....	2.016		-252.8	2 vol.:100		
Peroxide .....	34.02	1.442	-1.7	v.s.		
Hydrogen peroxide $\text{H}_2\text{O}_2$	34.02	1.442	-1.7	331:100		
Selenide .....	81.22	liq. 2.12	-64	vols.		
Iodine .....	126.92	4.95	113.5	0.03:1000		sol.-KI sol.
Iridium (ous)*chloride $\text{IrCl}_3$	228.56	10.18	Dec. 798			
Iridium(ie) chloride.. $\text{IrCl}_3$	299.47	5.30	Dec. 763			

<sup>1</sup> The anhydrous salt is referred to.

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)			
						Water, 20°C.	Hot water	Absolute alcohol, cold	Acids
Iron (see Ferrum)...	Fe	55.84	7-7.8	1530	3000	i	i	i	s-HNO <sub>3</sub>
Lead (see Plumbum)...	Pb	207.10	11.37	327.5	1620	0.04:100	i	i	s
Iodine...	I <sub>2</sub>	260.94	6.12	373	861	0.13:100	0.06:100	i	s-alk., HNO <sub>3</sub>
Lime (see Calcium)...	CaO	56.07	3.2	Red heat	...	i	i	i	v.s.
Litharge...	PbO	223.10	9.2	...	...	...	...	...	s
Lithium...	Li	6.94	0.53	186	>1200	Dec.	...	...	...
Carbonate...	Li <sub>2</sub> CO <sub>3</sub>	73.88	2.11	618	...	1:2:100	0.72:100	i	s
Chloride...	LiCl	42.40	2-2.07	613	Dec.	78.5:100 <sup>1</sup>	127:100 <sup>1</sup>	v.s.	s
Hydroxide...	LiOH	23.95	2.54	450	...	12.8:100	17.5:100	...	v.s.
Nitrate...	LiNO <sub>3</sub>	68.95	2.3-2.4	255	...	3:4	2:1	v.s.	...
Phosphate...	Li <sub>3</sub> PO <sub>4</sub>	115.84	2.54	837	...	0.04:100	...	...	...
Sulphate...	Li <sub>2</sub> SO <sub>4</sub>	109.94	2.21	860	...	35:100 <sup>1</sup>	30:100 <sup>1</sup>	s	s
Magnesium...	Mg	24.32	1.74	651	1110	...	Dec.	...	s
Ammon-phos...	NH <sub>4</sub> MgPO <sub>4</sub> ·6H <sub>2</sub> O	235.50	...	Dec.	...	1:15,000	...	...	s
Carbonate...	MgCO <sub>3</sub>	84.32	3.04	Dec.	...	0.01:100	...	...	s
Chloride...	MgCl <sub>2</sub> ·6H <sub>2</sub> O	203.33	1.56	Dec 118	...	54:100	128:100	1:2	s
Hydroxide...	Mg(OH) <sub>2</sub>	58.34	2.34	Dec.	...	0.003:1000	...	...	s
Nitrate...	Mg(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O	256.43	1.46	95	143	70:100 <sup>1</sup>	136:100 <sup>1</sup>	...	s
Oxide...	MgO	40.32	3.65	2800	...	0.001:100	...	...	s
Pyrophos...	Mg <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	222.69	2.6	...	...	...	...	...	s
Sulphate...	MgSO <sub>4</sub> ·7H <sub>2</sub> O	246.49	1.68	Red heat	...	45:100	85:100	s	s
Manganese...	Mn	54.93	7.2	1260	1900	Slowly	Dec.	...	s
Dioxide...	MnO <sub>2</sub>	86.93	4.7-5.0	...	...	i	i	i	s
Manganous...	MnCO <sub>3</sub>	114.93	3.13	Dec	...	...	...	...	s
Carbonat...	MnCl <sub>2</sub> ·4H <sub>2</sub> O	197.91	2.01	58.0	...	15:10	65:10	53:100	s
Chloride...	Mn(OH) <sub>2</sub>	88.95	...	...	...	...	...	...	s
Hydroxide...	Mn(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O	287.04	1.82	25.8	Dec.	57:100 <sup>1</sup>	v.s.	i	s
Nitrate...	MnO	70.93	5.18	1650	...	i	i	i	s
Oxide...	MnO	70.93	5.18	1650	...	...	...	...	s

Manganous Sulphide.....	MnSO <sub>4</sub>	151.00	3.25	700	.....	65:100 i	32:100 <sup>1</sup> i	i	s s-Aq. req.
Sulphide.....	MnS	87.00	3.99	Dec.	.....	.....	.....	.....	.....
Mercuric Bromide.....	HgBr <sub>2</sub>	360.44	6.05	237	Subl. 322	0.86:100	20:100	1.3	s
Chloride.....	HgCl <sub>2</sub>	271.53	5.44	277	300	1:50	78:100	0.8:100	s
Iodide.....	HgI <sub>2</sub>	454.47	6.27	259	349	.....	0.0004:-	.....	s
Nitrate.....	Hg(NO <sub>3</sub> ) <sub>2</sub> +½H <sub>2</sub> O	333.63	4.3	79	.....	Dec. <sup>1</sup>	.....	.....	s
Oxide.....	HgO	216.6	11.14	Dec.	red heat	.....	.....	.....	s
Sulphate.....	HgSO <sub>4</sub>	296.67	6.47	Dec.	.....	Dec. <sup>1</sup>	.....	.....	s
Sulphide.....	HgS	232.67	7.7-8.1	Dec.	.....	.....	.....	.....	s-Aq. req.
Mercurous Chloride.....	Hg <sub>2</sub> Cl <sub>2</sub>	472.12	7.15	302	Sub. 310	0.002:1000	.....	.....	i-HCl
Iodide.....	Hg <sub>2</sub> I <sub>2</sub>	655.04	7.70	Dec. 290	.....	v.s.	.....	.....	.....
Nitrate.....	Hg <sub>2</sub> NO <sub>3</sub> .H <sub>2</sub> O	280.63	4.78	70	.....	.....	.....	.....	.....
Oxide.....	Hg <sub>2</sub> O	417.22	8.75	Dec 100	.....	.....	.....	.....	.....
Sulphate.....	Hg <sub>2</sub> SO <sub>4</sub>	497.28	7.56	Dec 100	.....	.....	.....	.....	.....
Mercury.....	Hg	200.6	13.555	-39.87	356.9	.....	.....	.....	s-HNO <sub>3</sub>
Molybdenum.....	Mo	96.0	10.2	2620	3700	.....	.....	.....	.....
Chloride.....	MoCl <sub>5</sub>	273.90	.....	194	268	Dec.	.....	.....	.....
Oxide di.....	MoO <sub>3</sub>	128.0	6.4	.....	.....	.....	.....	.....	s-NH <sub>4</sub> OH
Oxide tri.....	MoO <sub>3</sub>	144.0	4.50	795	Sublimes	0.2:100	0.1:100	.....	s-NH <sub>4</sub> OH
Molybdic Anhydride.....	MoO <sub>3</sub>	144.0	4.50	795	.....	.....	.....	.....	s-NH <sub>4</sub> OH
Sulphide.....	MoS <sub>2</sub>	160.13	4.8	1185	.....	1:500	1:960	.....	s-HCl
Nickel Carbonyl.....	Ni(CO) <sub>4</sub>	58.68	8.90	1452	2900	.....	.....	.....	s
Nickelic hydroxide.....	Ni(OH) <sub>2</sub>	170.69	1.32	-25	43	.....	.....	.....	s
Nickelous Chloride.....	NiCl <sub>2</sub>	129.61	3.54	Sublimes	.....	62:100	88:100	.....	s-KCN
Cyanide.....	Ni(CN) <sub>2</sub>	110.70	4.36	.....	.....	.....	.....	.....	s-KCN
Hydroxide.....	Ni(OH) <sub>2</sub>	92.70	4.36	.....	.....	.....	.....	.....	s
Nitrate.....	Ni(NO <sub>3</sub> ).6H <sub>2</sub> O	290.80	2.06	56.7	136.7	1:2	v.s.	.....	s
Sulphate.....	NiSO <sub>4</sub> .7H <sub>2</sub> O	280.86	1.95	98	.....	1:3	7.6:10	.....	s
Sulphide.....	NiS	90.75	4.60	797	.....	.....	.....	.....	{ s-Aq. req. i-dil. HCl }
Nitrogen.....	N <sub>2</sub>	28.02	0.00126	-209.9	-195.8	0.0018:1 vol.	.....	.....	.....
Bromine.....	NBr <sub>3</sub>	253.77	.....	Liquid	Explores	.....	.....	.....	Dec.

<sup>1</sup> Requires free acid to prevent decomposition

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts sold to parts water)		
						Water, 20°C.	Hot water	Absolute alcohol, cold
Nitrogen.								
Chloride.	$\text{NCl}_3$	120.38	1.65	-161	71	l.s.		26:100
Nitride.	$\text{N}_3\text{O}$	30.01	liq. 1.27	-153	-153	5.1:100 vol.		vol.
Iodide.	$\text{NI}_3$	394.77	liq. 1.23	Explodes	-88	1 3:1 vol.	l.s.	4 2:1 vol.
Monoxide.	$\text{N}_2\text{O}$	44.01	liq. 1.23	-102.4				
Tetroxide.	$\text{NO}_2$	46.01	liq. 1.45	-9 3	22	Dec.		
Trioxide.	$\text{N}_2\text{O}_3$	76.02		-111	0	Dec.		
Nitric acid.	$\text{HNO}_3$	63.02	1.502	-42	88			Dec.
Nitric acid.	68%		1.414		121			Dec.
Nitrous acid.	$\text{HNO}_2$	47.03		-102	-89 4			
Nitrous oxide.	$\text{N}_2\text{O}$	254.8		39 5	100			
Osmium tetroxide.	$\text{OsO}_4$ (white)	32.00	0.00143	-215	-183	0.041		
Oxygen.								
Palladium:								
Chloride.	$\text{PdCl}_2$	177.62		Sublimes				s-alkalis
Hydrate.	$\text{Pd}(\text{OH})_2$	140.73						
Iodide.	$\text{PdI}_2$	359.91		300	Dec.			
Nitrate.	$\text{Pd}(\text{NO}_3)_2$	230.72						
Sulphate.	$\text{PdSO}_4 \cdot \text{H}_2\text{O}$	220.79		Dec. at Reduces				
Palladium	$\text{Pd}$	106.7	11.4	1355	2200	Dec.		
Ferchloric acid.	$\text{HClO}_4$	100.47	1.76	-35	19			s- $\text{HNO}_3$
Phosphine.	$\text{PH}_3$	34.05	liq. 0.746	-132 5	-85	l.s.		
Phosphoric:								
Acid.	$\text{H}_3\text{PO}_4$	98.05	1.83	42 4	Dec.			
Anhydride.	$\text{P}_2\text{O}_5$	142.05	2.39	563				
Chloride.	$\text{PCl}_3$	208.31		148	162	Combines		
Phosphorus.	$\text{P}$	124.16	1.83	45	280	Dec.		s- $\text{CS}_2$
Acid.	$\text{H}_3\text{PO}_3$	82.05	1.65	73.6	Dec.	v.s.		
Anhydride.	$\text{P}_2\text{O}_3$	110.05	2.14	22.5	173	v.s.		
Chloride.	$\text{PCl}_3$	137.40	1.57	-112	78	Dec.		
Red.	$\text{P}$	31.04	2.1	250 changes				i- $\text{CS}_2$

	451.191	2.43	D <sub>20</sub>	4300	v.s.	v.s.	v.s.	s-HCl s-Aq. regia
Platinic chloride	266.12	5.87	Dec. 581	4300	1	1	1	
Platinous chloride	195.2	21.5	1755		1	1	1	
Platinum								
Plumbic:								
Acetate.	379.29	2.55	280		1:2	2:1	3:3:100	s
Carbonate	267.20	6.47	Dec. 315		0.001:1000	1:1	1:20	s-dec.
Chloride	278.12	5.8	501	956	1:101	3:3:100		s
Chromate	323.10	6.0			0.0002 per Al	1		s
Hydroxide.	241.12				1 s.	1 s		s-alkalis
Oxide	223.20	9.21	587		1	1		s-alkalis
Peroxide	239.20	9.37	Dec.		1	1		
Phosphate	811.65	7.1	1014		1	1		s-HNO <sub>3</sub>
Sulphate	303.27	6.20	1170		1:22,000	v. l. s.		s-NH <sub>4</sub> C <sub>2</sub> H <sub>3</sub> O <sub>2</sub>
Sulphide	239.27	7.5	1115	1185	1	1		s-HNO <sub>3</sub>
Potassium	39.10	0.86	63.3	760	Dec.	Dec.	33:100	Dec.
Acetate	98.12	1.8	292		23.10	8.1		s
Acid tartrate	188.13		Dec.		0.4:100	7:100		
Alum.	948.84	1.73	84.5		11.100	22.7:100		
Arsenate	256.26				1.5	v.s.	4:100	
Arsenite	202.17				v.s.	1:1		Dec.
Bicarbonate	100.11		Dec.		1.4	1:1	1:1200	s
Bichromate	294.21	2.69	398	Dec.	1.10	1:1	1:300	s
Bromide	119.04	2.75	730	Sublimes	2.3	145:100		Dec.
Carbonate	138.19	2.29	891		11:10	v.s.	1:120	Dec.
Chlorate	122.55	2.32	368	Dec. 400	1.14	1:2	1:200	i-conc. HCl
Chloride	74.55	1.99	790	Sublimes	3.4:10	1:2		s
Chromate	194.20	2.73	975		63:100	79:100		s
Chromic alum	998.86				2.10	1:2		s
Cyanide	65.10	1.52	634		v.s.	122:100	0.87:100	s
Fluoride	58.10	2.48	880		v.s.	1 s.		s
Ferrocyanide.	329.17	1.89	Dec.		1:2.5	82:100		s
Ferrocyanide	422.31	1.83	Dec.		1:51	1:11		s
Hydroxide	56.10	2.04	380	Sublimes	112:100	311:100		s
Iodide	214.03	3.89	560		8:100	32:100		s
Iodide	166.03	3.12	773		14:10	223:100	1:70	s

<sup>1</sup> Anhydrous form.

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)			
						Water, 20°C.	Hot water	Absolute alcohol, cold	Acids
Potassium:									
Manganate	$K_2MnO_4$	197.13	2.11	333	Dec.	s	Dec.	i	s
Nitrate	$KNO_3$	101.10	1.92	297	•	1:3 3:1	2:1 v.s.	i	Dec.
Nitrite	$KNO_2$	85.10	2.13	232	•	s	s	•	s
Oxalate	$K_2C_2O_4 \cdot H_2O$	184.21	2.32	Red heat	•	v.s.	v.s.	v.s.	s
Oxide...	$K_2O$	94.19	2.71	Dec. 240	•	1:16	1:4	Dec.	s
Permanganate.	$KMnO_4$	158.03	2.34	96	•	1:4	v.s.	v.s.	s
Phosphate.	$KH_2PO_4$	136.13	3.99	Dec.	•	1:100	1:19	v.l.s.	s
Platinic chloride.	$K_2PtCl_6$	486.16	•	•	•	•	•	•	s
Pyroantimoniate	$K_2HSb_2O_7$	432.62	•	•	•	•	•	•	•
Silicate...	$K_2SiO_3$	154.25	•	976	•	s	s	•	Dec.
Sulphate...	$K_2SO_4$	174.26	2.66	1067	•	11:100	33:100	1	s
Acid sulphate	$KHSO_4$	136.17	2.35	210	Dec.	36:100	v.s.	•	s
Sulph-hydrate...	$KHS$	72.17	•	455	•	s	v.s.	s	Dec.
Sulphide	$K_2S$	110.26	1.81	471	•	v.s.	v.s.	•	Dec.
Sulphite...	$K_2SO_3 \cdot 2H_2O$	194.30	•	•	•	1:1	v.s.	i	Dec.
Tartrate	$K_2H_2C_2O_6$	226.22	1.98	Dec.	•	15:10	•	•	Dec.
Radium bromide	$RaBr_2$	386.24	•	728	•	s	•	0 4:100	s
Realgar	$As_2S_2$	214.06	3.5	•	•	i	i	•	s-alkalis
Rubidium:									
Carbonate.	$Rb_2CO_3$	230.88	•	837	•	v.s.	146:100	0 74:100	•
Chloride	$RbCl$	120.89	2.76	715	•	84:100	•	•	•
Sulphate	$Rb_2SO_4$	226.95	3.61	1060	•	43:100	82:100	•	•
Ruthenium oxide.	$RuO_4$	165.70	5.77	25.5	•	•	•	•	•
Selenic acid	$H_2SeO_4$	145.22	2.95	58	260	v.s.	•	•	s-HF and alkalis.
Silicic acid.	$Si(OH)_4$	96.33	•	•	•	l.s.	•	•	s-HF and alkalis.
Anhydride	$SiO_2$	60.06	2.2-2.65	>1470	•	i	i	i	s-HF and alkalis.
Bromide	$SiBr_4$	347.72	2.81	5	153	•	•	•	•
Chloride	$SiCl_4$	169.89	1.48	-70	59	Dec.	•	Dec.	Dec.





THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)			
						Water, 20°C.	Hot water	Absolute alcohol, cold	Acids
<b>Sodium:</b>									
Carbonate.....	$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$	286.15	1.46	Dec. 35	Dec.	21:100	45:100	1	Dec.
Carbonate.....	$\text{Na}_2\text{CO}_3$	105.99	2.53	851	Dec.	7:100	45:100	1	Dec.
Chlorate.....	$\text{NaClO}_3$	106.46	2.49	248	White heat	1:1	2:3:1	s	Dec.
Chloride.....	$\text{NaCl}$	58.46	2.16	804	White heat	1:3	4:10	1	i-conc. HCl
Chromate.....	$\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$	342.16	1.48	Dec. 19.85	318	42:100	s	s	s
Hydroxide.....	$\text{NaOH}$	40.00	2.13	318	White heat	109:100	288:100	s	s
Hypocaulphite.....	$\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$	248.20	1.68	Dec. 48	Dec.	1:1	2:1	1	Dec.
Iodide.....	$\text{NaI}$	149.93	3.67	651	18:10	8:10	3:1	s	s
Nitrate.....	$\text{NaNO}_3$	85.01	2.26	308	8:10	8:10	4:1	s	s
Nitrite.....	$\text{NaNO}_2$	69.01	2.17	271	271	8:10	v.s.	1	s
Oxide.....	$\text{Na}_2\text{O}$	61.99	2.27	.....	.....	v.s.	v.s.	s	s
Peroxide.....	$\text{Na}_2\text{O}_2 \cdot 8\text{H}_2\text{O}$	222.18	2.8	Dec. 30	Dec.	9:100	1:1	1	s
Phosphate.....	$\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$	358.21	3.58	34.6 Dec.	Dec.	v.s.	v.s.	s	s
Platinic chloride.....	$\text{Na}_2\text{PtCl}_6 \cdot 6\text{H}_2\text{O}$	562.06	2.50	Dec.	220 Dec.	1:2	3:1	s	s
Potass. tartrate.....	$\text{NaKC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$	281.51	1.79	75	.....	v.s.	v.s.	s	s
Pyroantimonate hydrated	$\text{Na}_4\text{Sb}_2\text{O}_7 \cdot \text{H}_2\text{O}$	462.39	.....	.....	.....	v.s.	v.s.	v.l.s.	s
Pyrophosphate	$\text{Na}_2\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$	446.19	1.82	77 Dec.	.....	6:100	9:10	1	Dec.
Stannate.....	$\text{Na}_2\text{SnO}_3 \cdot 4\text{H}_2\text{O}$	282.19	.....	.....	.....	61:100	s	.....	Dec.
Silicate.....	$\text{Na}_2\text{SiO}_3$	122.05	.....	1088	.....	.....	s	.....	s
Sulphate.....	$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	322.21	1.46	32.38 Dec.	Dec. 32.38	1:51	1:21	1	Dec.
Sulphate.....	$\text{Na}_2\text{SO}_4$	142.06	2.70	884	.....	19:100	50:100	1	Dec.
Sulphide.....	$\text{Na}_2\text{S}$	78.06	1.86	.....	.....	s	s	s	Dec.
Sulphite.....	$\text{Na}_2\text{SO}_3 \cdot 7\text{H}_2\text{O}$	252.17	1.56	Dec.	.....	1:41	1:11	1	Dec.
Stannic Chloride.....	$\text{SnCl}_4$	260.53	2.28	-30 2	114.1	Dec.	.....	.....	s-HCl

## PHYSICAL CONSTANTS

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Hydroxide	H <sub>2</sub> SnO <sub>3</sub>	169.02	Dec	i	s-acids, alkalis.
Oxide	SnO <sub>2</sub>	150.70	6 8-7.0	1130	s-NH <sub>4</sub> SH
Sulphide	SnS <sub>2</sub>	182.83	4 5	i	s-acids, alkalis.
Stannous Chloride	SnCl <sub>2</sub> ·2H <sub>2</sub> O	225.95	250	Dec.	s
Hydroxide	H <sub>2</sub> SnO <sub>2</sub>	153.02	Dec.	i	s-acids, alkalis.
Oxychloride	Sn <sub>2</sub> OCl <sub>2</sub> ·2H <sub>2</sub> O	360.95	Dec.	i	s-conc.
Oxide	SnO	134.7	6 1-6.9	970	HCl
Sulphide	SnS	150.77	4.97	1090	s-H <sub>2</sub> CO <sub>3</sub>
Strontium Bromide	Sr Br <sub>2</sub>	87.65	2 54	1150	s
Carbonate	SrCO <sub>3</sub>	247.45	2 21	800	s
Chloride	SrCl <sub>2</sub> ·6H <sub>2</sub> O	147.62	3 6	643	s
Hydrate	Sr(OH) <sub>2</sub>	266.63	1 92	Dec 1141	s
Nitrate	Sr(NO <sub>3</sub> ) <sub>2</sub>	121.64	3 63	832	s
Oxide	SrO	211.64	2 99	570	s
Peroxide	SrO <sub>2</sub>	103.62	4 7	Dec 645	s
Sulphate	SrSO <sub>4</sub>	119.63	3 46	2430	s
Sulphide	SrS	183.68	3 96	Dec 1580	s
Sulphuric Acid	S	32.07	1 96	Dec.	s-HCl
Common	S	32.07	2.07	112 8	s
Sulphuretted hydrogen	H <sub>2</sub> S	34.08	Liq. 0.96	444.6	i-CS <sub>2</sub> s-CS <sub>2</sub>
Sulphuric Acid	H <sub>2</sub> SO <sub>4</sub>	98.08	1.842	327	v.l.s.
Anhydride	SO <sub>3</sub>	80.07	1.92	35	Dec.
Chloride	SCl <sub>2</sub>	102.99	1 62	34 dec.	Dec.
Fuming acid	H <sub>2</sub> SO <sub>4</sub>	178.16	1 9	Dec.	Dec.
Tetrachloride	SCl <sub>4</sub>	173.91	-30	-30	Dec.
Sulphurous Acid	H <sub>2</sub> SO <sub>3</sub> + Aq	64.07	-72 7	-10	v.s.
Anhydride	SO <sub>2</sub>	64.07	-72 7	-10	v.s.

<sup>1</sup> Anhydrous form. <sup>2</sup> Normal anhydrous phosphate melts at 957°C <sup>3</sup> The anhydrous salt melts at 884°C

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THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)		
						Water, 20° C.	Hot water	Absolute alcohol, cold
Sulphurous Chloride	$\text{S}_2\text{Cl}_2$	135.06	1.68	-80	136	Dec.	Dec.	s
Tantalum	Ta	181.5	16.6	2850	>4100	Dec.	Dec.	s
Tantalic Acid	$3\text{Ta}_2\text{O}_5 \cdot 5\text{H}_2\text{O}$	1419.08						
Tantalum Anhydride	$\text{Ta}_2\text{O}_5$	443.0	8.73	Dec. 1470				
Tantalum Chloride	$\text{TaCl}_5$	358.79	3.68	221	245	Dec.		
Tantalum Fluoride	$\text{TaF}_5$	276.50	4.74	96.8		s		
Telluric Acid								
Telluric Anhydride	$\text{H}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$	229.55	3.44	Dec. 160		s		
Tellurium	$\text{TeO}_3$	175.50	5.08	Dec.	Dec.	i		
Tellurous	Te	127.5	6.24	452	1390	i		
Telluric Acid	$\text{H}_2\text{TeO}_4$	177.52	5.66	Dull red	Below 700	l.s.		s
Telluric Anhydride	$\text{TeO}_2$	159.50		175	327	Dec.		s
Telluric Chloride	$\text{TeCl}_4$	198.42	2.57	-48				
Telluric Hydride	$\text{H}_2\text{Te}$	129.52	11.86	303.5	1850	s		
Thallium	Tl	204.0	7.1	272	Dec.	i	27:100	
Thallium Carbonate	$\text{Ti}_2\text{CO}_3$	264.00		25	Dec.	v.s.		
Thallium Trichloride	$\text{TiCl}_3$	310.38		300	Dec.	v.s.	18:100	
Thallium Oxide	$\text{Ti}_2\text{O}_3$	424.80	6.77	632	Dec.			
Thallium Sulphate	$\text{Ti}_2\text{SO}_4$	504.87						
Thorium								
Thorium Chloride	$\text{ThCl}_4$	373.98	4.59	820		Dec.		
Thorium Nitrate	$\text{Th}(\text{NO}_3)_4 \cdot 12\text{H}_2\text{O}$	696.63				v.s.		
Thorium Oxide	$\text{ThO}_2$	264.15	9.69	>2800		i		
Tin, see Stannum	Sn	119.0	7.29	231.9	2260	i	i	
Titanic Chloride	$\text{TiCl}_4$	189.73	1.73	-30	135	Dec.	Dec.	s-HCl
Titanium Fluoride	$\text{TiF}_4$	123.9	2.798	Liquid				



THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg C.	Boiling point, deg C.	Solubility (parts solid to parts water)		
						Water, 20°C	Hot water	Absolute alcohol, cold
<b>Zinc:</b>								
Ferrocyanide.	$\text{Zn}_2\text{Fe}(\text{CN})_6$	342.64	3.05	Dec. 125	...	i	...	...
Hydrate.	$\text{Zn}(\text{OH})_2$	99.39	4.67	446	...	i	...	...
Iodide.	$\text{ZnI}_2$	319.24	4.67	364	...	v.s.	v.s.	...
Nitrate	$\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	297.49	5.6	>1800	...	115:100 <sup>1</sup>	v.s.	...
Oxide	$\text{ZnO}$	81.38	5.6	>420	...	i	i	...
Phosphide.	$\text{Zn}_3\text{P}_2$	258.19	4.55	...	...	...	...	...
Sulphate	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	287.55	1.95	Dec. 740	...	135:100	655:100	...
Sulphide	$\text{ZnS}$	97.44	3.3-4.2	1850	...	i	i	...
<b>Zirconium</b>	$\text{Zr}$	90.6	4.15	...	...	...	...	...
Bromide	$\text{ZrBr}_4$	410.28	...	Sublimes	Red heat	...	...	...
Chloride	$\text{ZrCl}_4$	232.83	...	Sublimes	White heat	Dec.	...	...
Fluoride	$\text{ZrF}_4 \cdot 3\text{H}_2\text{O}$	220.65	...	...	...	v.s.	...	...
Nitrate.	$\text{Zr}(\text{NO}_3)_4$	338.64	...	...	...	s	...	...
Oxide.	$\text{ZrO}_2$	123.00	5.71	2700	...	i	i	...
Silicate.	$\text{ZrSiO}_4$	182.90	...	...	...	i	...	...
Sulphate.	$\text{ZrSO}_4$	186.67	...	Dec at red	...	s	v.s.	...

<sup>1</sup> The general form of this table is taken from CREMER and BICKSELL's "Chemical and Metallurgical Handbook," but many more compounds have been listed, the boiling- and melting-point tables checked, and all the molecular weights recalculated by the 1925 atomic weight table on a basis of O = 16. Where a melting point greatly exceeding 100°C is given for a hydrated salt, the melting point is that of the anhydrous form.

**Magnetic Susceptibilities of the Elements<sup>1</sup>** $h$  = magnetic force $I$  = intensity of magnetization.= magnetic moment per cm.<sup>3</sup>= pole strength per cm.<sup>2</sup> $B$  = magnetic induction, or flux density =  $h + 4\pi I$ . $\mu$  = permeability =  $B/h$ . $H$  = susceptibility =  $I/h = \frac{\mu - 1}{4\pi}$ . $B$ ,  $h$  and  $I$  are in lines per cm.<sup>2</sup> and are vector quantities.Unit:  $4\pi$  lines start from a unit magnetic pole.Coercivity,  $h_B = 0$ , is the demagnetizing force required to make  $B = 0$  after saturation.Coercive force is the demagnetizing force required to make  $B = 0$  after some particular field strength.Remanence,  $B_H = 0$ , is the induction remaining when the magnetizing force is removed after saturation.The work done, i.e., hysteresis loss,  $Q_h$ , in taking a cm.<sup>3</sup> of magnetic material through a magnetic cycle between the limits

$$+H_s \text{ and } -H_s = \int_{-H_s}^{+H_s} h dI = \frac{1}{4\pi} \int_{-H_s}^{+H_s} h dB.$$

STEINMETZ's empirical formula for the hysteresis loss is  $\eta B_{\max}^n$ , where  $\eta$  is a constant and  $n = 1.6$  (usually). The magnetic properties of a material depend not only on its chemical composition, but on its previous mechanical and heat treatment; thus only general characteristics are indicated below.

Good permanent magnet steel contains about 0.5 per cent. W and 0.6 per cent. C. Cast iron, chilled from 1000°C., may also be used, but the results will never be so good as with steel. The HEUSLER alloys (Cu, Mn, Al) are remarkable in showing high magnetism when the components do not. With an alloy of 96.6 per cent. Fe and 3.4 Si (Yensen's alloy), the permeability rises to over 60,000 when the alloy is annealed at 1100°C.

**PERMEABILITY  $\mu$** 

Material	$h = 0.5$	$h = 1$	$h = 5$	$h = 20$	$h = 60$	$h = 150$
Swedish wrought iron....	2500	3710	2060	736	274	120
Annealed cast steel.....	1450	3500	2100	747	280	123
Unannealed cast steel....	490	970	1700	680	270	122
Cast iron.....	.....	.....	81	182	117	65
Magnet steel {	hardened.....	.....	68 <sup>2</sup>	78	193	100
	tungsten.....	.....	80 <sup>2</sup>	119	204	100
	.....	.....	.....	.....	.....	.....

The figures given are only roughly comparative and can only be used as a general working guide. If exact results on particular specimens are wanted, laboratory determinations are necessary.

<sup>1</sup> KAYE and LABY, "Physical and Chemical Constants."<sup>2</sup> At  $h = 15$ .<sup>3</sup> At  $h = 10$ .

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Material	Coercivity	Remanence	$H_c$	Hysteresis loss $Q_c$ , ergs/cm. <sup>3</sup>
Swedish wrought iron.....	0.8	4,000	200	6,700
Annealed cast steel.....	0.97	7,100	151	11,700
Unannealed cast steel.....	2.08	9,000	156	20,400
Cast iron.....	11.9	4,230	155	34,300
Magnet steel { hardened.....	52.6	11,700	234	211,000
tungsten.....	27.5	9,880	505	116,000

The figures given are only roughly comparative and can only be used as a general working guide. If exact results on particular specimens are wanted, laboratory determinations are necessary.

Material	$h_{max}$	Induction, $B$ , for		$\mu_{max}$	For $h_{max}$		
		$h_{max}$	$h = 100$		Coer	Reman	Hyst. loss, ergs/cm. <sup>3</sup>
Mild steel.....	129	18,190	17,700	8,350	0.6	10,300	4,900
Steel, 2.8% Cr, 0.8% C.					56.0	6,400 <sup>2</sup>	
Steel, 5.5% W, 0.6% C, hardened at 770°					72.0	7,000 <sup>2</sup>	280,000
Steel, 7.7% W, 1.9% C, hardened at 800°					85.0	4,700 <sup>2</sup>	
Steel, 4% Mo, 1.2% C, hardened at 800°					85.0	6,700	
Iron.....	50	17,100		1,750	2.2 <sup>1</sup>	53% $B_{max}$	
Silicon iron, 0.6% Si.	55	16,000		1,900	1.6 <sup>1</sup>	43% $B_{max}$	
Silicon iron, 4.5% Si.	56	15,100		2,500	1.2 <sup>1</sup>	39% $B_{max}$	
Electrolytic iron	210	21,250			18.0	10,000	
Electrolytic iron heated to 1200° C.			16,000		2.5	12,500	
HADFIELD'S Mn steel <sup>3</sup> .				1.3-1.5		Small	
Nickel, annealed.....	100	5,137		296	8.0	3,570	
Cobalt.....	140	10,000	9,500	174	12.0	3,400	
Cobalt, 96%.....	114	8,237	7,800	177			19,000
HEUSLER alloy <sup>4</sup> .....	92	2,735		115			

The figures given are only roughly comparative and can only be used as a general working guide. If exact results on particular specimens are wanted, laboratory determinations are necessary.

<sup>1</sup>  $H = 10$

<sup>2</sup> Bar magnet.

<sup>3</sup> 12 per cent Mn, 1 per cent. C.

<sup>4</sup> Mn 24, Al 16, Cu 60

An alloy of iron and boron Fe<sub>2</sub>B is highly magnetic, as is also MnB (16.66 per cent B). *Trans. VIII Int. Cong. App. Chem.*

$$H = Ih = \frac{\mu - 1}{4\pi}, H = 0 \text{ for a vacuum.}$$

The susceptibility depends very much upon the purity of the material, especially upon the absence of iron. It appears to be a periodic property of the atomic weight.



Elem. solids	$H \times 10^{-6}$	Elem. solids	$H \times 10^{-6}$	Elem. solids	$H \times 10^{-6}$
Al <sup>2</sup>	+0.65	P.	-0.9	U	+0.9 <sup>1</sup>
Sb	-0.95	Pt.	+1.32	U.	+1.5
As	-0.31	K	+0.4	Zn	-0.15
Bi.	-1.4	Rh.	+1.1	Zr	-0.45
B.	-0.71	Ru	+0.56	Li and	
Cd	-0.17	Sc.	-0.32	Br	-0.41
Cr	+3.7	Si	-0.12	Hg	-0.19
Cb	+1.3(?)	Ag	-0.2	N <sup>2</sup> (liq.)	+0.28
Cu	-0.087	Na.	+0.51	O (liq.)	+0.324
Au	-0.15	S.	-0.5	H <sub>2</sub> O (15°)	-0.80
I.	-0.36	Ta	+0.8	Gases	
Ir	+0.15	Tc.	-0.32	Air (16°)	+0.032
Fe	see p. 229	Ti.	-0.3 <sup>1</sup>	A	-0.010
Pb	-0.12	Th.	+1.8	He	-0.002
Mg	+0.55	Sn.	+0.025	H	-0.008
Mn	+10.6(?)	Tl.	+2.0 <sup>1</sup>	N	+0.024
Mo.	+0.04	W	+0.22	O	+0.123

The figures given are only roughly comparative and can only be used as a general working guide. If exact results on particular specimens are wanted, laboratory determinations are necessary.

<sup>1</sup> Approximate only.

<sup>2</sup> Probably this paramagnetism is due to contained iron, for the more nearly chemically pure Al becomes the less its magnetism. This value is given by HONDA, *Annalen der Physik*, 1910, p. 1045.

There is a critical temperature above which magnetic permeability is very small; in the case of iron it is one of the recalcrescence temperatures. The critical temperature is not perfectly definite, but depends upon whether the material is being heated or cooled.

Fe, 690–895°C.; Ni, 95 per cent., 300–377°C.; magnetite, 582°C.; HEUSLER alloys about 300°C.; Co, 1102°C.; Cu, 72°C.; Zn, 300–350°C., possibly also at 170°C.; Sn, 18° and 161°C.; Cd, 64.9°C.

### Electromagnetic Separation

#### MAGNETIC PERMEABILITY (Fe = 100,000)

Iron . . . . .	100,000	Oxide of manganese...	167
Magnetite . . . . .	40,000	Black oxide of nickel...	106
Spathic iron ore...	767	Manganese sulphate....	100
Hematite . . . . .	714	Ferrous sulphate.....	78
Oolitic iron ore....	593	Nickelous oxide.....	35
Limonite . . . . .	296		

The figures given are only roughly comparative and can only be used as a general working guide. If exact results on particular specimens are wanted laboratory determinations are necessary.

Magnetic Permeability (in descending scale).

FARADAY'S arrangement.

Paramagnetic: Fe, Ni, Co, Mn, Cr, Ti, Pd, Pt, Os.

Diamagnetic: Bi, Sb, Zn, Sn, Cd, Hg, Pb, Ag, Cu, As, U, Ir, W.

Iron = 2000; air = 1; Bi = 0.998.

**ACTION OF THE WETHERILL MAGNET ON MINERALS FOUND  
IN PLACER SANDS, TOGETHER WITH THEIR SPECIFIC  
GRAVITY<sup>1</sup>**

Non-magnetic	Sp. gr.	Separated by current of ½ amp. or less	Separated by current of 2 amp.	Separated by current of 3½ amp.
<b>Mineral:</b>				
Iridium.....	22.0			
Iridosmium.....	19.0			
Gold.....	15.6-19.3			
Platinum.....	14-19	Platinum <sup>2</sup>	Platinum <sup>2</sup>	Platinum <sup>2</sup>
Amalgam.....	14.0			
Mercury.....	13.5			
Lead.....	11.0			
Cinnabar.....	8.1			
Galena.....	7.5			
Wolframite.....	7.2-7.5	Cast iron 7.5		
Cassiterite.....	7.0	Josephinite 7		Cassiterite 7
Scheelite.....	6.0		Hematite 5	
Crocoite.....	6.0			
Columbite.....	5.3-7.3			
Pyrite.....	5.0	Magnetite 5.2	Ilmenite 5	Monazite 5
Molybdenite.....	4.8			
Zircon.....	4.7			
Barite.....	4.3-4.6		Chromite 4.3-4.6	Pyrrhotite 4.5
Corundum.....	4.0		Rutile 4.2	Corundum 4
Cyanite.....	3.6		Limonite 4	Brookite 4
Diamond.....	3.5		Garnet 3-4	
Topaz.....	3.5		Pyroxene 3.2-3.6	
Fluorite.....	3.25		Epidote 3.5	Spinel 3.5-4
Apatite.....	3.2		Titanite 3.5	
Spodumene.....	3.1			
Beryl.....	2.7		Chrysolite 3.3	
			Tourmaline 3	
			Siderite 3	
			Serpentine 2.5	

<sup>1</sup> R. H. RICHARDS, "Ore Dressing," Vol. IV.<sup>2</sup> Probably due to iron.

**Minerals Which Become Quite Magnetic on Roasting<sup>1</sup>**

Sulphides oxidizing roast without carbon		Oxides and carbonates reducing roast with carbon	
Pyrite	FeS <sub>2</sub>	Hematite,	Fe <sub>2</sub> O <sub>3</sub>
Marcasite,	FeS <sub>2</sub>	Siderite,	FeCO <sub>3</sub>
Chalcopyrite,	FeCuS <sub>2</sub>	Wolframite,	FeMnWO <sub>4</sub>
Bornite,	FeCu <sub>3</sub> S <sub>3</sub>	Chromite,	FeCr <sub>2</sub> O <sub>4</sub>
Arsenopyrite,	FeAsS		

**Magnetic Separation**

It is found that in extracting magnetic iron sulphide from blende, that a better separation results if the ore is warm to the hand than if it is cold. In roasting concentrates prior to magnetic separation the temperature should not be allowed to rise to over 900 to 1000°F. as it is desired to keep the blende

<sup>1</sup> R. H. RICHARDS, "Ore Dressing," Vol. II.

unroasted. The current for exciting a Dings separator for the first separation is about 5 amp. at 225 volts, treating about 60 tons per day; and for finishing, about 12 amp. at 225 volts, treating 40 to 45 tons per 24 hr. The current, however, may run up to 19 amp. at times. (E. G. DEUTMEN, *Eng. and Min. Journ.*, June 28, 1919.)

In the electromagnetic treatment of monazite sand it is of the greatest importance to keep the strength of the current constant.

## SECTION IV

### CHEMICAL DATA

#### CHEMICAL LAWS AND DEFINITIONS

**Avogadro's.**—Equal volumes of all gases and vapors contain the same number of ultimate particles or molecules at the same temperature and pressure.

**Conservation of Energy.**—Whenever a change in mode of manifestation of energy takes place, the total amount of energy remains a constant.

**Dalton's.**—See multiple proportions.

**Definite Proportions.**—A chemical compound always contains the same constituents in the same proportion by weight.

**Diffusion of Gases.**—The rate of diffusion of gases is approximately inversely proportional to the square roots of their specific gravities.

**Dulong and Petit.**—The product of the atomic weight and the specific heat of the same element is a constant.

**Gay-Lussac's.**—When gases or vapors react on each other the volumes both of the factors and the products of the reaction always bear to each other some simple numerical ratio.

**Indestructibility of Matter** (Lavoisier).—Whenever a change in the composition of substances takes place, the amount of matter after the change is the same as before the change (NOTE.—This "law" does not hold for all cases, such as those involving radioactivity.)

**Isobares.**—Elements of the same atomic weight and different atomic number.

**Isomerism** is the identity of percentage composition with difference of physical or of both chemical and physical qualities. The difference may be in molecular weight (polymerism), or of order of union of atoms in the molecule (metamerism), or of position of the atoms in space (stereo-isomerism).

**Isotropic.**—Having the same properties in all directions: said of a medium with respect to elasticity, conduction of heat, etc.

**Mariotte's.**—The volume of a gas is directly proportional to the absolute temperature and inversely proportional to the absolute pressure upon it.

**Metamerism.**—Having the same percentage composition, but with a different order of union of atoms in the molecule. Thus, methyl ether and ethyl alcohol are metamers, both being  $C_2H_6O$ , but one is  $(CH_3)_2O$  and the other is  $CH_3\cdot CH_2OH$ .

**Multiple Proportions (Dalton).**—If two elements *A* and *B* form several compounds with each other, and we consider any fixed mass of *A*, then the different masses of *B* which combine with the fixed mass *A* bear a simple ratio to one another.

**Periodic.**—The properties of an element are periodic functions of the atomic weight.

**Polymerism.**—An identity of percentage composition but a difference in molecular weight. Compounds totally dissimilar are thus polymers, as aldehyde,  $\text{CH}_3\cdot\text{CHO}$ , and butyric acid,  $\text{CH}_3\cdot\text{CH}_2\cdot\text{CH}_2\cdot\text{COOH}$ , one being  $\text{C}_2\text{H}_4\text{O}$  and the other  $\text{C}_4\text{H}_8\text{O}_2$ . But polymerism may also be like allotropism in elements, as in paraldehyde  $(\text{CH}_3\cdot\text{CHO})_3$ , where the compound itself forms a complex molecule.

### The Structure of the Atom<sup>1</sup>

The great difference between the present theory in regard to the constitution of matter and that held when most of us were students seems to make no apology necessary for introducing a short discussion of this subject here.

The nineteenth century theory of the constitution of matter postulated indivisible bodies called atoms, with properties that were repeating functions of their weights, which weights represented the proportions in multiples of which they combined with each other. The atom of hydrogen was supposed to be the smallest mass capable of existing. However, CROOKES eventually showed that the cathode rays consist of negatively charged corpuscles the mass of which is less than one-thousandth that of a hydrogen atom. Later the Curies, BECQUEREL, RUTHERFORD and SODDY showed that the atoms of some elements were certainly unstable, and that they disintegrate spontaneously giving out negatively charged corpuscles or electrons such as constitute CROOKES' cathode rays ( $\beta$  particles), positively charged particles ( $\alpha$  particles) of the same mass as helium atoms, and a radiation (known as  $\gamma$ -rays) that has since been shown to consist of X-rays of short wave-length.

It may here be noted that although the  $\alpha$  and  $\gamma$  rays travel with speeds comparable with that of the X-rays that the last have the power of ejecting electrons from atoms, whereas the first two never do so.

The basis of late nineteenth century chemistry was the "so-called" periodic law of MENDELEEF, that the atomic weight of any element determines its properties, or, that the properties of the elements are periodic functions of the atomic weight. Roughly, if the elements are arranged in recurring "octaves" according to increasing atomic weights, elements of similar properties fall in columns. While this is so generally true that MENDELEEF was enabled to prophesy the discovery of certain elements with certain properties, it is not without its exceptions.

<sup>1</sup> This short discussion is largely founded on the papers by Dr. SAUL DUBHMAN in the *General Electric Review*.

**MENDELEJEFF'S PERIODIC SYSTEM OF THE ELEMENTS\*\***  
(Containing Atomic Weights, Atomic Numbers and Isotopic Radioactive Elements)

[illegible]

Au 197.3 (79)	Hg 200.6 (80)	Tl 204.4	Pb 207.2 RaD 210.2	Bi 209.0 RaE 210.2	Po 210.0 RaF 210.2 AcC <sub>1</sub> 211.2 AcA 215.2 ThC <sub>2</sub> 212.2 ThA 216.2 RaC <sub>1</sub> 214.2 RaA 218.2
AcEm 219.2 ThEm 220.2 Rn 222.0	(86)	AcD 207.2 (82) ThD 208.2	AcB (83) 211.2 ThB 212.2 ThD <sub>2</sub> 208.2 RaB 214.2 RaD <sub>2</sub> 210.2	AcC (84) 211.2 ThC <sub>1</sub> 212.2 RaC 214.2	(85)
AcX 223.2 ThX 224.2 Ra 225.96 MesTh <sub>1</sub> 228.2	(87)	Ac 227.2 MesTh <sub>2</sub> 228.2	RdAc 227.2 RdTh 228.2 Io 230.2 Th 232.15 U <sub>X</sub> 234.2	Pa 234.2 (91)	U <sub>11</sub> 234.2 U <sub>1</sub> 238.17

\* Be = Gl. † Cb = Nb. ‡ Welsbach's aldebaranium, Urbain's neoytterbium. § Welsbach's cassiopeium. Atomic weights listed in **Bold** figures. Atomic Numbers listed in *Italics* in parentheses. \*\* Courtesy, *General Electric Review*.

For instance, according to atomic weight, iodine should come before tellurium, while according to its properties it comes after it. Argon and potassium form another such exceptional case. On the other hand we have elements of different atomic weights, yet inseparable chemically. These exceptions the newer theory of "atomic numbers" attempts to explain.

Reverting to MENDELEEFF's work, and considering also the elements discovered since his time, if they are arranged in order of increasing atomic weight it is observed that the first twenty elements have similar properties at every eighth element. Thus sodium resembles lithium, phosphorus is like nitrogen and chlorine like fluorine. But beginning with argon, we must pass over 18 elements before we come to one similar to it (krypton), and then we have another group of 18 before we come to another like it, xenon. In the next series, however, comes a separate system, the rare earths, most of them so nearly alike chemically and physically that their separation is a matter of extreme difficulty. Then after another short group of normal elements come the radioactive elements, whose atoms disintegrate spontaneously in appreciable amounts in appreciable times. As said above, there are discrepancies in any arrangement by atomic weight and the view is now held that it is a so-called atomic number that is the true factor in determining the properties of the elements. In the table on p. 288, taken from the *General Electric Review*, are shown the elements, their atomic weights and the atomic numbers (in brackets). What these last are will be explained later (p. 295).

In general the members of the 0 group are inert (valency 0); those of group 1 monovalent,  $E_2O$ ,  $EH$ ; of group 2, divalent; etc. The members of the fifth, sixth and seventh groups possess two sorts of valences: with H they form compounds of the type  $EH_3$ ,  $EH_2$  and  $EH$  respectively, while with O, they form compounds of the type  $E_2O_3$ ,  $EO_2$  and  $E_2O_7$  respectively.

The most electropositive elements are in group 1, the most electronegative in group 7, and in any given group, those of low atomic number are more electropositive than those of high. This property is connected with the tendency to give out electrons. A heated carbon filament gives off negative electricity, which J. J. THOMSON showed was in the form of free electrons similar to those making up cathode rays.

RICHARDSON showed that platinum and other metals give off electrons when heated and that the number of electrons emitted increases rapidly as the temperature rises. For every metal there exists a "heat of vaporization" ( $w$ ) which represents the amount of work required to separate an electron from the main body. The more electropositive the metal the smaller is  $w$ .

When metals are illuminated by radiation of frequency  $\nu$  electrons are emitted with a velocity  $v$  (photoelectric effect) expressed by the equation  $\frac{1}{2}mv^2 = \bar{V}e = h\nu - p$  where  $m$  = mass of electron,  $e$  = charge on electron,  $h = 6.56 \cdot 10^{-27}$  erg. sec.,  $p$  = work necessary to get the electron out of the metal and  $\bar{V}$  = retarding potential necessary to prevent emission.



Two types of inelastic collision between electrons and molecules of *metallic vapor* exist. One type results in a displacement of an electron in the atom and the other type in the removal of an electron from the atom. The potential differences in volts through which an electron must fall to acquire the proper velocity to suffer these two types of collision are known as the resonance and ionization potentials of the metallic vapor. In many cases these potentials can be computed from a knowledge of  $\nu$ , some characteristic frequency in the spectrum of the metal. The following direct determinations by an electrical method are summarized by Foote and Mohler.

Element	Resonance * (Volts)		Ionization (Volts)	
	Theoretical	Observed	Theoretical	Observed
Li . . . . .	1.84	...	5.36	...
Na . . . . .	2.09	2.12	5.11	5.13
K. . . . .	1.61	1.55	4.32	4.1
Rb . . . . .	1.58	1.6	4.16	4.1
Cs. . . . .	1.45	1.48	3.87	3.9
Mg . . . . .	2.70	2.65	7.61	7.75
Ca. . . . .	{ 1.84 2.92	{ 1.93 3.0	6.08	6.04
Zn. . . . .	4.01	4.1	9.34	9.5
Cd . . . . .	3.78	3.88	8.95	8.92
Hg . . . . .	4.86	4.9	10.38	10.35
Tl . . . . .	1.07	1.07	...	7.3
Pb . . . . .	...	1.26	...	8.0
As. . . . .	...	4.7	...	11.5

From the facts above noted we may deduce that the electron is a constituent of all atoms, and that some atoms have a greater affinity for electrons than do others. The atoms with the lowest electron affinity are the most electropositive. There are also further considerations upon which are based calculations as to the number of electrons in the atom, some of which are discussed below.

### High-frequency Spectra of the Elements

When cathode rays of low velocity strike the surface of any metal, the latter emits a continuous spectrum of X-rays with wave lengths of about  $1 \times 10^{-8}$  cm. The spectrum is cut off at an upper limit of frequency ( $V_m$ ) which is connected with the maximum voltage of the X-ray tube by the relation.

$$eV = hV_m$$

As the voltage of the tube is raised above a definite value, the anti-cathode material emits a characteristic X-radiation classified according into three groups *K*, *L* and *M*. In 1913, N. G. J. MOSELY measured the wave lengths of the *K* and *L* series for most elements and found that if to each element he assigned a number agreeing with its place in the periodic table (as far as Au = 79), then

$$\sqrt{V} = a[N - N_0]$$

where  $V$  is the frequency,  $a$  and  $N_0$  are constants and  $N$  is the atomic number. According to RUTHERFORD  $N$  is the magnitude

of the positive charge on the nucleus of the atom and hence must also correspond to the number of electrons in the atom, since each electron carries a negative charge and on a neutral atom the number of negative charges must equal the number of positive charges.

#### VARIOUS ELEMENTS, THEIR ATOMIC WEIGHTS, AND WAVE-LENGTHS OF THEIR CHARACTERISTIC X-RAYS

Element	Atomic weight	Wave-length	Remarks
Calcium	40.1	$3.36 \times 10^{-8}$ cm. $3.09 \times 10^{-8}$ cm.	Strong K radiation Weak radiation
Titanium	48.1	$2.76 \times 10^{-8}$ cm. $2.525 \times 10^{-8}$ cm.	Strong K radiation Weak radiation
Vanadium	51.1	$2.52 \times 10^{-8}$ cm. $2.30 \times 10^{-8}$ cm.	Strong K radiation Weak radiation
Chromium	52.0	$2.30 \times 10^{-8}$ cm. $2.09 \times 10^{-8}$ cm.	Strong K radiation Weak radiation
Manganese	54.9	$2.11 \times 10^{-8}$ cm. $1.92 \times 10^{-8}$ cm.	Strong K radiation Weak radiation
Iron	55.9	$1.945 \times 10^{-8}$ cm. $1.765 \times 10^{-8}$ cm.	Strong K radiation Weak radiation
Cobalt	59.0	$1.80 \times 10^{-8}$ cm. $1.63 \times 10^{-8}$ cm.	Strong K radiation Weak radiation
Nickel	58.7	$1.66 \times 10^{-8}$ cm. $1.505 \times 10^{-8}$ cm.	Strong K radiation Weak radiation
Copper	63.6	$1.55 \times 10^{-8}$ cm. $1.40 \times 10^{-8}$ cm.	Strong K radiation Weak radiation

The various constants of the electron as determined by R. A. MILLIKAN are as follows (*Proc. Nat. Acad. Sci.*, vol. 3, p. 314).

The electron.....	$e = 4.774 \pm 0.005 \times 10^{-10}$
The Avogadro constant.....	$N = 6.062 \pm 0.006 \times 10^{23}$
Number of gas mols per cc at $0^\circ$ , 76 cm.	$n = 2.705 \pm 0.003 \times 10^{19}$
Kinetic energy of translation of a mol at $0^\circ$	$E_0 = 5.621 \pm 0.006 \times 10^{-14}$
Change of translational mol. energy per $^\circ\text{C}$ .	$= 2.058 \pm 0.002 \times 10^{-16}$
Mass of an atom of H.	$m = 1.662 \pm 0.002 \times 10^{-24}$
Planck's element of action.....	$h = 6.547 \pm 0.013 \times 10^{-27}$
Wien const. of spectral radiation.....	$C_2 = 1.4312 \pm 0.0030$
Stefan-Boltzmann const. of total radiation..	$= 5.72 \pm 0.034 \times 10^{-12}$
Grating spacing in calcite.....	$d = 3.030 \pm 0.001\text{A}$
Diameter of atom, average, about.....	$= 2.0 \times 10^{-8}$
Mass of an electron.....	$= 9.01 \times 10^{-28}$

#### Radioactive Phenomena

The periodic table indicates that as the atom becomes more and more massive, there is a periodic recurrence of the same arrangement of the outermost electrons in the atom. The observations on high frequency spectra and scattering of alpha particles lead to the conclusion that the positively charged nucleus is of extremely small dimensions compared with those of the atom itself, and furthermore, that the chemical properties of the elements depend only upon the magnitude of the positive charge on the nucleus.<sup>1</sup>

<sup>1</sup> The diameter of the nucleus is probably less than  $\frac{1}{100,000}$  the diameter of the atom, yet the nucleus contains practically the entire mass of the atom.

We now pass to the discussion of observations which show us that not only is the atomic weight of but secondary significance in determining the position of an element in the periodic table and that we may have several atomic weights for the same element, but that the structure of the nucleus itself is quite complicated.

It has already been mentioned that in the radioactive elements discovered by BECQUEREL and MME. CURIE, we have unstable atoms which disintegrate spontaneously, as has been shown conclusively by RUTHERFORD and SODDY. After a certain average period of existence, which may range from over a thousand years, as in the case of uranium ( $U_1$ ) to a millionth of a second, as in the case of  $RaC_1$ , the atom undergoes a sudden explosion and yields an atom which possesses totally distinct properties. The disintegration is detected by the expulsion either of alpha or of beta particles.<sup>1</sup> Accompanying the expulsion of beta particles there is also observed in a number of cases, an emission of gamma rays. These are electromagnetic pulses of extremely short wave-length (about  $10^{-9}$  cm.) and are probably due to the bombardment of the atoms of the radioactive substance itself by the beta particles.

Further investigation has shown that the rate at which these atoms disintegrate is absolutely uninfluenced by any of the factors, such as temperature, pressure, illumination with ultra-violet or X-rays, etc., which are used in controlling the rate of ordinary chemical and physical reactions.

Since the disintegration of any atom always yields an atom occupying a different place in the periodic table we must conclude that the change actually occurs in the nucleus itself. Furthermore, as electrons and alpha particles are emitted during the disintegration, it follows that the nucleus, small as it is, consists of negatively charged corpuscles and helium nuclei, packed close together. How is it possible for positive and negative charges to remain in equilibrium under such conditions? Probably COULOMB's law fails completely for distances as small as those which exist inside the nucleus. It may indeed become reversed; that is, positive and negative charges repel each other at distances which are less than  $10^{-13}$  cm.

It has been found that each of the radioactive products belongs to one of three well-defined disintegration series whose starting points are uranium, thorium, and actinium respectively. Fig. 1 illustrates diagrammatically the manner in which the members of these series appear to be related.

When mesothorium II disintegrates, it yields radiothorium and as a beta particle is expelled during the transformation there is no change in atomic weight. Radiothorium is chemically allied to thorium and non-separable from it. These facts lead to the conclusion that radiothorium belongs to Group IV and mesothorium II must therefore belong to Group III.

<sup>1</sup> The alpha particle has the same mass as an atom of helium; but differs from the latter in possessing two unit positive charges,  $2E = 9.54 \times 10$  E.S.U. The beta particles correspond in mass and electric charge to the electrons, units of negative electricity,  $E = 4.77 \times 10$  E.S.U.

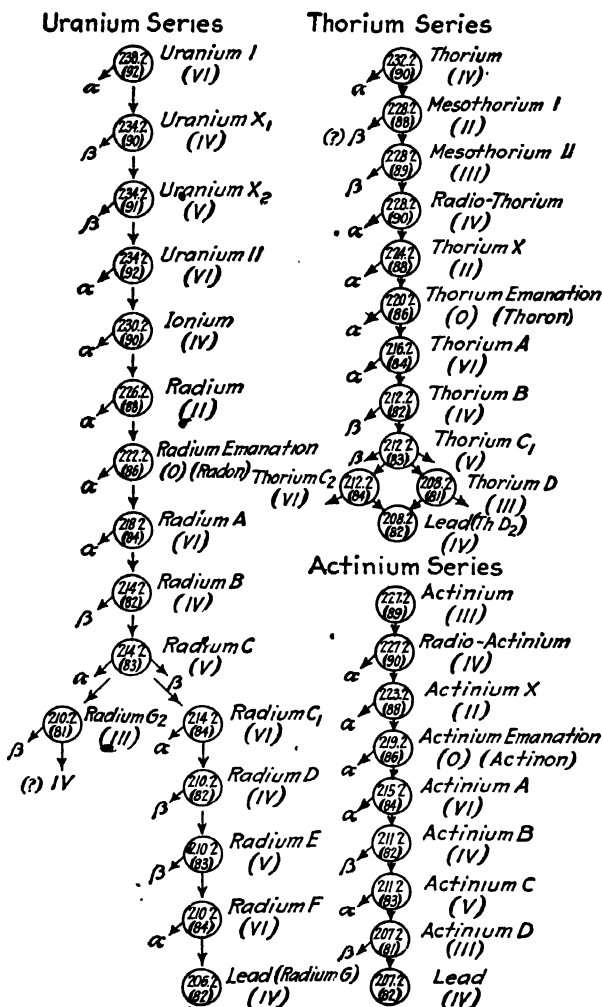


FIG. 1.—Method of disintegration of radioactive elements.

Passing to thorium *X*, we here again come to an element which is chemically similar to radium, thus placing it in Group II. The atom of thorium *X* expels an alpha particle and yields thorium emanation, a gas which is *inert chemically*, and condenses at low pressures between  $-120^{\circ}\text{C}$ . and  $-150^{\circ}\text{C}$ . The emanation resembles, therefore, the rare gases of the argon group.

Thorium emanation is the first member of the group of transformation products that constitute the thorium "active deposit." They are indicated in Fig. 1 as thorium *A*, *B*, *C*, *C*<sub>1</sub> and *D*.

The most noteworthy feature about these products is the fact that individual members of each series appear to be chemically indistinguishable from certain members of the other series. Owing, however, to the difference in previous history of these atoms, they *possess different atomic weights* and also differ in period of existence. In other words, we have here cases of elements that are absolutely inseparable by all chemical methods so far devised, and yet differ in that respect which has hitherto been taken to be the most important characteristic of an element—its atomic weight. SODDY, who has drawn attention to these cases, has named these products *isotopes*, since they occupy the same place in the periodic table. As shown in the table in Fig. 1, there are three other isotopes of thallium, and no less than six isotopes of lead. These results are thus in accord with the conclusion already advanced above, that *the most characteristic property of any element is its atomic number*, and not the atomic weight. The different isotopes of any element may therefore be regarded as consisting of atoms which are all alike as far as the number of electrons, their arrangement, and the charge on the nucleus; but the arrangement of electrons and alpha particles in the nucleus of each of these atoms is evidently not the same. Hence arise the differences in mass and average life.

**Soddy's Law of Sequence of Changes.**—A comprehensive survey of the chemical properties of the different radioactive elements has led SODDY and FAJANS independently to an interesting and extremely important generalization which enables them to assign these isotopes to their places in the Periodic Table.

It will be remembered that an alpha particle is a helium atom with two positive charges. By its expulsion, therefore, the atom must lose two positive charges, and the atomic weight must decrease by four units. Similarly, the expulsion of a beta particle means the loss of a negative charge or, what is equivalent, the gain of one positive charge; and since the mass of the beta particle is extremely small compared with that of the atom, there is practically no decrease in atomic weight. Now in the Periodic Table the valency for oxygen, an electronegative element, increases regularly as we pass from Group 0 to Group VIII, while that for hydrogen, an electropositive element, decreases, *i.e.*, the electropositive characteristic

increases by one unit for each change in the group number as we pass in any series from left to right. Furthermore, in each group the electropositive character increases regularly with increasing atomic weight.

These considerations led SODDY and FAJANS to this conclusion:

*The expulsion of an alpha particle from any radioactive element leads to an element which is two places lower in the Periodic Table (and has an atomic weight which is four units less) while the emission of a beta particle leads to an element which is one place higher up, but has the same atomic weight.*

It is possible, therefore, to have elements of the same atomic weight but possessing distinctly different chemical properties, and, on the other hand, since the effect of the emission of one alpha particle may be neutralized by the subsequent emission of two beta particles, it is possible to have two elements which differ in atomic weight by four units (or some multiple of four) and yet exhibit chemically similar properties.

As an illustration, let us consider the Uranium Series. Uranium 1 belongs to Group VI. By the expulsion of an alpha particle we obtain uranium  $X_1$ , an element of Group IV. This atom in turn disintegrates with the expulsion of a beta particle. Consequently uranium  $X_2$  must belong to Group V. In this manner we can follow the individual changes that lead to the different members of the series, and by means of the generalization of SODDY and FAJANS we cannot only assign to each element its place in the Periodic Table but also its atomic weight, as has been done in Fig. 1.

This generalization has been of material assistance in elucidating some of the difficult problems in the study of the disintegration series. More than this, it has led to the intensely interesting conclusion that the end product of each of the three radioactive series is an isotope of lead. The results of the most recent work on the atomic weight of lead are in splendid accord with this deduction, as it has been found that lead which is of radioactive origin, has a slightly lower atomic weight than ordinary lead.<sup>1</sup>

In a couple of cases the isotope has not been definitely isolated, but there can hardly be any doubt of its existence. Thus, the disintegration product of radium  $C_2$  must be an element of Group IV, but the evidence for its existence is very meager.

### General Conclusions Regarding the Structure of Atoms

It is obvious that any theory of the structure of the atom which we can form at present must be regarded as only a first approximation. But there are some conclusions which can be drawn, with a certain degree of assurance from the above observations.

First, the smallest mass of which we have knowledge is the electron. This either carries a unit negative charge or the

<sup>1</sup> *J. Am. Chem. Soc.*, 36, 1329, 1914.

unit negative charge ( $4.77 \times 10^{-10}$  e.s.u.) actually constitutes the mass, which is about  $\frac{1}{1800}$  the mass of the hydrogen atom. Its radius would be about  $2 \times 10^{-13}$  cm.

The unit positive charge is identical with the hydrogen ion. Its mass is 1. When it engages with a single negative charge it becomes a hydrogen atom. All others of the so-called elements consist of hydrogen ions forming a nucleus, a corresponding number of electrons revolving about them, and a number of extra hydrogen or helium atoms known as "the packing."

The hydrogen ion is often called a proton, and the number of protons in an atom determines the atomic number.

The atom is therefore a miniature planetary system, consisting of a charged nuclear sun about which revolve the electrons, each carrying or consisting of a negative charge,  $-e$ . The charge on the nucleus is  $+Ze$ , where  $Z$  is the atomic number. The electrons are arranged in different groups, known as shells, of different binding energies. In a solid, these atoms are vibrating about their equilibrium positions, with a frequency of about  $6 \times 10^{12}$  cycles per second. Molecules are made up of one or more atoms. Those elements found as gases at ordinary temperatures consist of molecules of 2 atoms each, except those of the rare gases, which are monatomic. Volatilized metals have monatomic vapors.

As to the "packing," there is much discussion. SIR ERNEST RUTHERFORD believes it to be held closely about the nucleus—inside the nearest of the electron orbits, and whether it does consist of hydrogen and helium atoms is sometimes questioned.<sup>1</sup>

The important matter is, that there is a nucleus of protons, a number of free electrons equal to the number of the protons, and a number of combined protons and electrons (probably helium and hydrogen). The free electrons in the outer shell are those which produce chemical reactions, and there apparently cannot be more than eight in a shell, after which a new series begins with a shell further out, thus accounting for Mendeleef's "octaves."

Why the atomic weight of hydrogen is 1.008 instead of 1 is apparently due to a certain energy of the free electron which is lost when the protons, electrons, and hydrogen and helium atoms set up joint establishments. But after getting to helium, all atoms should have integral weights.

That they do not is explained by the existence of isotopes. If different atoms of the same element have different atomic weights but similar chemical reactions, they are *isotopes*. Thus we have lead atoms with the same number of free positive charges within and of electrons without the nucleus, but with a varying number of these bound subatomic couples or positive and negative charges packed about the nucleus. Isotopes are atoms which have the same atomic number—that is, the same number of free positive charges within the nucleus and

<sup>1</sup> It is interesting to note that there is apparently an element of atomic weight 3, nebulium, in some of the nebulae, which may be the packing of some of the elements of higher atomic weight.

opposed electrons outside it—but not the same number of hydrogen or helium atoms packed about the nucleus. Therefore, the atomic weights of isotopes differ. And while each atom is integral, mixtures of isotopes give fractional weights. Even if we had equal portions of actinium lead 206, common lead 207, thorium lead 208 and radium lead 210, we should have an atomic weight of the mixtures of 207.7 and there is nothing to make the proportions of the different isotopes either constant or equal. So we generalize by saying that fractions in atomic weights are due to mixtures of isotopes.

We must beware not to confuse isotopes with allotropic modifications such as is shown in the various forms of phosphorus and sulphur. There we have different geometrical arrangements of atoms within the molecules or crystals. In isotopes the differences are confined to the packing about the nuclei of the atoms. And we must not confuse the presence of isotopes with processes of radioactivity. When free positive charges and entrained electrons are thrown from a radium atom, for instance, the atomic number is reduced, and we have the transmutation of an element, the new element ceasing to be isotopic with the first.

It stands to reason that all the various isotopic forms of lead have the same chemical properties, because chemical properties are on the outside of the atom. We have in chemical activity exchanges of electrons on the outer shells of atoms, the holding of pairs of electrons in common by combined atoms and the wandering of electrons from one atom to another, thus producing ions, but in chemical processes the free positive charges in the nucleus and the H and He atoms packed within or about it are not disturbed. In radioactivity they are shot off, but not in chemical processes. So it is generally agreed, and it would seem fair to say, that the chemical properties of all the isotopic variations of an element are the same.

There is no reason why atoms of different elements should not have the same mass or atomic weight, and indeed this is so, especially among the heavier elements. For instance, radium D, actinium C and polonium all have the atomic weight of 210, but have as atomic numbers respectively 82, 83, and 84. These are not isotopes. They are called isobares.

### Aston's Great Work

Very important in the field of isotopes is the work of PROF. F. W. ASTON of Cambridge University. He tried, in 1914, to break up a gaseous element that shows a considerable deviation from an integral number in its atomic weight, and began with neon, using diffusion methods. He believed it consisted of mixed isotopes of atomic weights 20 and 22, and his experiments confirmed him in this belief. The method of diffusion is very slow, and he followed this work by the use of SIR J. J. THOMSON'S method of positive ray analysis, and he then brought out the amazing conclusions that no fewer



than twenty elements consist of mixed isotopes the mass of each of which is invariably a whole number. A memorandum of these may be of interest.

Element	Atomic no.	Atomic wt.	Minimum number of isotopes <sup>1</sup>	Masses of isotopes in order of their intensity <sup>1</sup>
H	1	1.008	1	1.008
He	2	3.99	1	4
B	5	10.9	2	11, 10
C	6	12	1	12
N	7	14.01	1	14
O	8	16	1	16
F	9	19	1	19
Ne	10	20.2	2	20, 22, (21)
Si	14	28.3	2	28, 29, (30)
P	15	31.04	1	31
S	16	32.06	1	32
Cl	17	35.46	2	35, 37, (39)
A	18	39.88	(2)	40, 36
As	33	74.96	1	75
Br	35	79.92	2	79, 81
Kr	36	82.92	6	84, 86, 82, 83, 80, 78
I	53	126.92	1	127
Xe	54	130.2	5 (7)	129, 132, 131, 134, 136, (128, 130?)
Hg	80	200.6	(6)	(197 to 200), 202, 204

<sup>1</sup> Numbers in parenthesis are provisional only.

Lithium proved to be a mixture of isotopes 6 and 7. Sodium is simple, apparently only of 23. Potassium shows a strong line at 39, and a weak one at 41. Rubidium shows two, at 85 and 87, respectively. Although the atomic weight of caesium, 132.81, indicates complexity, no line except that at 133 has been distinguished.

PROF. W. D. HARKINS undertook the search for isotopes of chlorine, the atomic weight of which remains persistently around 35.5 and has always stood in the way of any hypothesis of integral weights. He used the diffusion method, and described it in the *Journal of the American Chemical Society*, August, 1921, vol. 43, No. 8. Since the speed of diffusion varies inversely as the square root of the density, it stands to reason that by shooting Cl, for instance, through a porous material, the lighter isotopes, if present, will tend to pass through more rapidly than the heavier. And the fruit of 7 years' labor is confirmatory of this. Repeated experiments showed the remaining chlorine which did not pass through the porous material to increase in atomic weight in the measure of 0.0318.

His first effort at separation was by means of a centrifugal machine, which was unsuccessful, but by employing diffusion apparatus, using churchwarden pipe stems and special tubes of clay, a separation of chlorine into heavier and lighter fractions was accomplished. He calculated the proportion of isotopic chlorine having the atomic weight of 37 derived from

## X-RAY LATTICES OF METALS

Aluminum.....	Cubic face centered	Gold.....	Cubic face centered	Potassium.....	Cube centered
Antimony.....	Hexagonal, two interpenetrating face centered lattices	Indium.....	Hexagonal, close packed	Rhodium.....	Cubic face centered
Beryllium.....	Hexagonal, close packed	Iron.....	Cube centered	Ruthenium.....	Hexagonal close packed
Cadmium.....	Hexagonal, close packed	Lead.....	Cubic face centered	Silver.....	Cubic face centered
Calcium.....	Cubic face centered	Lithium.....	Cube centered	Sodium.....	Cube centered
Chromium.....	Cube centered	Magnesium.....	Hexagonal close packed	Tantalum.....	Cube centered
Cobalt.....	Cubic face centered	Mercury (-46°C).....	Simple rhombohedral	Tin (gray).....	Cubic face centered
Cobalt $\beta$ .....	Hexagonal close packed	Molybdenum.....	Cube centered	Tin (ordinary).....	Tetragonal
Copper.....	Cubic face centered	Nickel.....	Cubic face centered	Titanium.....	Cube centered
Germanium.....	Cubic diamond type	Nickel $\beta$ .....	Cube centered	Tungsten.....	Cube centered
		Platinum.....	Cubic face centered	Zinc.....	Hexagonal close packed

the pure HCl which he put through the apparatus to be 23 per cent.

BRÖNSTED, of Copenhagen, evaporated mercury in vacuo upon a surface cooled by liquid air. It stands to reason that the lighter atoms which are single in mercury vapor would evaporate more readily and condense on the cool surface, and he actually found that the density of the condensed fraction was slightly less than the residue.

As an example of the force needed to drive satellites of hydrogen from nitrogen atoms as achieved in RUTHERFORD's experiment by the impact of alpha particles from radium C upon the nuclei of nitrogen atoms, it is computed that if the base of each impact were magnified to 1 cm. square, there would be a blow of  $10^{27}$  in kilograms. That's a billion times a billion times a billion times 2.2 lb. and then a lot more, on something the size of a child's thumb nail.

Examples of the manner in which the properties of the elements are progressive functions of the atomic nuclei are shown in the tables of the Ca-Sr-Ba, and Fl-Cl-Br-I families which follow:

Element	Calcium	Strontium	Barium	
Atomic mass	40	88	137	
Specific gravity	1.6	2.5	3.6	
Carbonate dissociates; temperature	600°C.	1100°C.	1400°C.	
Grams of hydroxide soluble in a liter of water at 15°C.	1.32	18	50	
Heat of formation of chloride; units	170	185	195	

Element	Fluorine	Chlorine	Bromine	Iodine
Atomic mass	19	35.5	80	127
Boiling temperature	-187°C.	-33°C.	59°C.	184°C.
Specific gravity	1.15 (liquid)	1.5 (liquid)	3.2 (liquid)	5 (solid)
Union with hydrogen takes place.	In the dark at ordinary temperatures.	In sunlight	At red heat.	At red heat but incompletely.
Heat of formation of hydrogen compound.	37.6 heat units.	22	8	-6.1
Stability of hydrogen compound	Most stable.	Decomposed at 1500°C.	Decomposed at 800°C.	Decomposed at 180°C.

The "atomic volume" is defined at the number of cubic centimeters occupied by a mass equal to the atomic weight, divided by the density. Small atomic volumes will in general indicate low coefficients of thermal expansion, high boiling points, and high heat of vaporization.

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## INTERNATIONAL ATOMIC WEIGHTS, 1930

Element	Symbol	Weight	Valence <sup>1</sup>	Electro-chem. equivalents, g. per amp.-hr.	Melting points deg. C.	Boiling points deg. C. visible ebullition
Aluminum...	Al	26.97	3	0.3353	658.7	1800.0
Antimony...	Sb	121.77	3	1.5133	630.5	1460.0
Argon...	A	39.94	0		-189.2	-186.0
Arsenic....	As	74.93	3	0.9322	814	450.0 <sup>2</sup>
Barium...	Ba	137.36	2	2.5625	850.0	
Beryllium...	Be	9.02	2		1350	
Bismuth...	Bi	209.0	3	2.5991	271.0	1440.0
Boron...	B	10.82	3		2300.0	3500 <sup>2</sup>
Bromine...	Br	79.92	1	2.9817	-7.2	58.75
Cadmium...	Cd	112.41	2	2.0969	320.9	778.0
Caesium...	Cs	132.81	1		26.0	
Calcium...	Ca	40.07	2	0.7475	810.0	
Carbon...	C	12.00	4	0.1115	> 3500.0	3700
Cerium...	Ce	140.13	4		640	
Chlorine...	Cl	35.46	1	1.3229	-101.6	-37.6
Chromium...	Cr	52.01	3	0.6468	1615	2200.0
Cobalt...	Co	58.94	2	1.1000	1610 <sup>2</sup>	
Columbium...	Cb	93.1	5		1950	
Copper...	Cu	63.57	2	1.1858	1083.0	2100.0
Dysprosium	Dy	162.46				
Erbium...	Er	167.74				
Europium...	Eu	152.0				
Fluorine...	F	19.0	1	0.7089	-223.0	-187.0
Gadolinium	Gd	157.26				
Gallium...	Ga	69.72	3		29.8	
Germanium	Ge	72.60	4		958.5	
Gold...	Au	197.2	3	2.4524	1063.0	2100
Hafnium...	Hf	178.6	4			
Helium...	He	4.002	0		< -272.2	-268.8
Holmium...	Ho	163.5				
Hydrogen...	H	1.008	1	0.03761	-259.1	-252.8
Indium...	In	114.8	3		155.0	1000
Iodine...	I	126.93	1	4.7355	113.5	184.34
Iridium...	Ir	193.1	4		2350.0	2850
Iron.....	Fe	55.84	2	1.0416	1535	2450.0
Krypton...	Kr	82.90	0		-169.0	-151.7
Lanthanum	La	138.90	3		826.0	
Lead...	Pb	207.22	2	3.8651	327.5	1525.0
Lithium...	Li	6.94	1	0.2589	186.0	500
Lutecium <sup>4</sup>	Lu	175.0				
Magnesium	Mg	24.32	2	0.4537	651.0	1120.0
Manganese...	Mn	54.93	2	1.0247	1260	1900.0
Mercury...	Hg	200.61	2	3.7422	-38.87	357.0
Molybdenum	Mo	96.0	2	1.7908	2620.0	3350

<sup>1</sup> In those cases in which a metal has two valences, the valence given corresponds to the electrochemical equivalent, and may not necessarily be the commoner one.

<sup>2</sup> Sublimes. <sup>3</sup> Commercial metal about 1480°C. <sup>4</sup> Or cassiopeium.

INTERNATIONAL ATOMIC WEIGHTS, 1930. *Continued*

Element	Symbol	Weight	Valence <sup>1</sup>	Electro-chem. equivalents, g. per amp.-hr.	Melting points deg. C.	Boiling points deg. C. visible ebullition
Neodymium	Nd	144.27	3		840 0	
Neon.....	Ne	20.18	0		-248 7	-239
Nickel.....	Ni	58.69	2	1 0948	1452 ± 3	2450
Niton.....	Nt	222 0	0			
Nitrogen....	N	14 008	3	0 1742	-209.9	-195.7
Osmium.....	Os	190 8	4		2700.0	2950
Oxygen.....	O	16 00	2	0.2985	-218.4	-183.0
Palladium...	Pd	106 7	2	1.9904	1555.0	2540
Phosphorus..	P	31 02	5		44.1	287 0
Platinum....	Pt	195 23	4	1 8209	1755 0	2650
Polonium....	Po	210	6		1800 0	
Potassium....	K	39 095	1	1.4586	62.3	667 0
Praseodymium..	Pr	140 92	3	.....	940.0	
Radium.....	Ra	225 97	2		960.0	
Radon.....	Rn	222			-71 0	
Rhodium.....	Rh	102 91	4		1955 0	2750
Rubidium....	Rb	85 44	1		38 5	696
Ruthenium...	Ru	101 7	4		2450 0	2780
Samarium....	Sa	150.43	3	....	1350.0	
Scandium....	Sc	45 1	3		1200 0(?)	
Selenium....	Se	79 2	2	1 4774	218 5	690 0
Silicon.....	Si	28 06	4	0.2617	1420 0	3800
Silver.....	Ag	107 88	1	1 0248	960 5	1955.0
Sodium.....	Na	22 997	1	0 8580	97 5	742.0
Strontium...	Sr	87 63	2	1 6334	>800	
Sulphur....	S	32 06	2	0 5981	112 8 - 119.0	444 5
Tantalum....	Ta	181 5	5		2850 0	
Tellurium...	Te	127 5	2	2 3783	452.0	1390.0
Terbium.....	Tb	159 2	3			
Thallium....	Tl	204 39	3		303.5	1700 0 <sup>2</sup>
Thorium....	Th	232 12	4	.....	1845.0	
Thulium....	Tm	169 4				
Tin.....	Sn	118 70	2	2 2142	231 9	2270.0
Titanium....	Ti	47 9	4	0.4468	1800.0	2700
Tungsten...	W	184 0	6	1 1416	3267	3700
Uranium....	U	238 14	6	.....	<1850 0	3100
Vanadium....	V	50 96	5	.....	1710 0	
Xenon.....	Xe	130.2	0		-140.0	-109 0
Ytterbium...	Yb	173 6			1800 0(?)	
			0			
Yttrium....	Yt	88 92	3		1490 0	
Zinc.....	Zn	65 38	2	1 2196	419 4	907.0
Zirconium...	Zr	91.22	4		1700 0	

<sup>1</sup> In those cases in which a metal has two valences, the valence given corresponds to the electrochemical equivalent, and may not necessarily be the commoner one. <sup>2</sup> Also given as 1280°C.

A SHORT ACCOUNT OF THE COMMON ELEMENTS<sup>1</sup>

**Aluminum.**—Atomic weight, 26.96; trivalent; sp. gr., cast, 2.56; rolled, 2.66. A silver-white metal; breaks with crystalline fracture. Melts at 657°C.; volatilizes at a very high temperature; specific heat from 0° to 100°C., 0.2270 (mean); latent heat of fusion, 100 cal.; coefficient of linear expansion, 0.0000231; heat conductivity, 31.33 (Ag = 100). Is friable at 530°C. The tensile strength of cast aluminum is about 15,000 lb. per sq. in., but this may be increased by drawing to 35,000 lb. per sq. in. Its conductivity is about 58 (Ag = 100).

The metal cannot be reduced with carbon except at very high temperatures; but forms a carbide  $Al_4C_3$ ; and a nitride  $AlN$ . It is reduced by sodium from its compounds. Said to be paramagnetic, susceptibility  $0.6 \times 10^{-6}$ . Is very malleable between 100° and 150°C. Is notable for the lightness of its alloys, and for its energetic reduction of oxides of other metals (thermit process). It cannot be produced by direct electrolysis in aqueous solution but is deposited electrolytically from a solution of its oxide in cryolite. The oxide forms the base of most artificial gems.

**Antimony.**—Atomic weight, 121.8; trivalent usually; sp. gr. 6.71; melts at 632°C., and volatilizes at about 1,500°C. Is in no degree malleable or ductile; its electric conductivity is 4.2 (Ag = 100). Has extremely crystalline structure; coefficient of linear expansion, along axis 0.0000168; normal to axis 0.0000089. It may readily be crushed to powder. Hydrochloric acid has a slight solvent action on it; nitric acid converts it to the pentoxide; sulphuric acid first oxidizes it and then converts it to sulphate. Chlorine reacts directly with the metal, forming anhydrous chloride. The classic process for the recovery of antimony is its liquation as sulphide,  $Sb_2S_3$ , from rich ores and the subsequent throwing down of the antimony by melting with scrap iron. It is also recovered by subjecting the ore to an oxidizing roast, driving off the antimony in fume, which is caught and reduced to metal. Antimony can also be recovered by lixiviation of the ores with sodium sulphide, obtaining either  $Na_3SbS_3$  or  $Na_3SbS_4$ . From these solutions it can be regained either chemically or by electrolysis. Another important source of antimony is in refining argentiferous lead. Before mixing in zinc for the PATTINSON process the lead is oxidized slowly for some time to purify it (softening process). The slag thus formed runs high in antimony from which it is recovered as antimonial lead.

In refining crude antimony (not hard lead) the crude metal is fused with 8 to 12 per cent. of  $Sb_2S_3$  and 4 to 5 per cent. of  $NaCl$  to bring it up to 98 to 99 per cent., and then it is given a final purifying by "starring," in which it is melted in the presence of  $Sb_2S_3$  and soda ash. No iron must be allowed to get into it during this process; so the iron ladles, etc., are kept well covered with whitewash.

<sup>1</sup> For the ordinary properties, see the preceding table.

**Argon.**—Occurs in the air to the extent of 0.935 per cent. It can be prepared by passing atmospheric nitrogen, free from oxygen and moisture, over red-hot magnesium ribbon; magnesium nitride is thus formed while the argon does not combine.

**Arsenic.**—Atomic weight 74.96; trivalent usually; sp. gr., crystalline 5.73, amorphous 4.71; a brittle steel-colored metal, volatilizes at 450°C., without melting. The metal and the pentavalent compounds are not poisonous, but the metal easily oxidizes and the pentavalent form easily reduces to the extremely poisonous trivalent form. Forms a very volatile hydride  $\text{AsH}_3$ , which serves as the basis for the famous MARSH test. Most of the arsenic on the market is recovered from flue dust, in which the arsenic concentrates. This is roasted in reverberatories and the roasted arsenious oxide condensed in large chambers.

**Barium.**—The properties of this metal are still in doubt, as it is probable that it has not yet been prepared in a high degree of purity. The impure form is prepared by reducing the oxide with magnesium. The peroxide,  $\text{BaO}_2$ , formed by heating  $\text{BaO}$  to 500°C. in the presence of air, serves as the basis of hydrogen peroxide manufacture. At a still higher temperature it again gives off oxygen.

**Beryllium.**—Atomic weight, 9.02; bivalent; sp. gr. 1.842. A hard, lustrous, white, malleable metal. Melts at 1278°C. Does not volatilize at 1900°C. Hardness, over 6. Burns like magnesium when in powder or ribbon. Withstands water better than magnesium, but this apparent inertness may be due to a film of oxide. Prepared by electrolyzing a mixture of sodium and beryllium fluorides, or by decomposition of the fluoride by sodium, potassium or magnesium. Is also produced by the electrolysis of sodium-beryllium fluoride at 200°C., followed by smelting the flaky metal produced. Has highest heat of fusion of any metal, 277 cal. Derives its former name, glucinum, from the sweetish taste of its compounds.

**Bismuth.**—Atomic weight, 209; trivalent; sp. gr., 9.80; the metal is neither malleable nor ductile; it melts at 266°C. and volatilizes between 1100 and 1450°. Electric conductivity, 1.3 ( $\text{Ag} = 100$ ). This metal is remarkable in that it expands on solidifying; its sp. gr. is about 10.055 just above the melting point. It is the most diamagnetic material known. Is obtained: (1) by liquation in crucibles or retorts of ores carrying native bismuth; (2) by reduction processes, using  $\text{Na}_2\text{CO}_3$  as a flux, beside  $\text{CaO}$  and  $\text{FeO}$ , since the fusion temperature of the slag must be low; (3) as a by-product of electrolytic lead refining; (4) as a by-product of steam Pattinsonizing (HULST process); (5) as a result of the wet treatment of the last oxide coming from the cupellation of lead-silver bullion. Some of its alloys melt at remarkably low temperatures (see fusible metals under "alloys").

**Boron.**—The element is found in nature as boric acid and borax. It is obtained by reduction as a brown amorphous powder, which, on dissolving in molten aluminum, separates

on cooling in crystalline form, said to rival the diamond in hardness. The suboxide is an energetic deoxidizer, recommended by WEINTRAUB for insuring high-conductivity copper castings.

**Bromine.**—Occurs in the mother liquors of certain salt-wells in the United States and at Stassfurt, Germany. It is liberated from these liquors by the action of chlorine, or by direct electrolysis. It is, at ordinary temperatures, a fuming red liquid of unbearable odor, from which it takes its name. It is more active than iodine and less than chlorine.

**Cadmium.**—Atomic weight, 112.4; always bivalent; sp. gr., cast, 8.60; white metal of bluish tinge, intermediate in hardness between tin and zinc. Melts at 320°C.; boils at 778°C., so can be separated from zinc by volatilization. Is precipitated from solution by zinc. Is remarkable for its fusible alloys: thus, 2 parts Bi, 1 part Sn, 1 part Pb melt at 93.75°C.; but with 10 per cent. Cd added melt at 75°C., while Cd 14.3, Sn 19.0, Pb 33.1 and Bi 33.6 melt at 66°C. Its metallurgy is simply that of a by-product of zinc. It is greatly concentrated in the first zinc dust formed in roasting the ores. The cadmium may then be freed from the zinc in a wet way owing to the fact that cadmium is precipitated from neutral solution on metallic zinc. The cadmium may then be redissolved and the cadmium freed from the last zinc by electrolysis, if a very pure metal be desired. If this is not necessary, advantage is simply taken of the fact mentioned above, that CdO is more volatile than ZnO, and also that CdO reduces at a lower temperature than does ZnO, and that Zn precipitates Cd from neutral solution.

**Cæsium.**—Of no commercial value. Atomic weight, 132.8. Discovered by KIRCHOFF in the Durkheim mineral water. Its spectrum contains two characteristic blue lines, whence its name.

**Calcium.**—Atomic weight, 40.07; bivalent; sp. gr., 1.55. A lustrous, silvery-white brittle metal. It is less malleable than the alkali metals; shows a crystalline fracture. It melts *in vacuo* at 810°C. It forms a hydride,  $\text{CaH}_2$ ; a nitride,  $\text{Ca}_3\text{N}_2$  and a carbide,  $\text{CaC}_2$ . It is a powerful deoxidizer. Cannot be reduced by carbon. The metal can be cut with a knife and will scratch lead but not calc spar.

**Cerium.**—Atomic weight, 140.25; sp. gr., 6.77. It has an iron-gray color, is soft, being somewhat harder than lead, is malleable and easily rolled. Fuses at about 800°C. Its most remarkable property is that of combining with heavy metals, such as iron or copper, to form dense but easily oxidizable alloys (the pyrophoric alloys). Fine wire made from the metal burns with a brilliancy even exceeding that of magnesium. It dissolves easily in dilute acids, but only to a limited extent in cold concentrated sulphuric or nitric acid. It will reduce the oxides of most metals or metalloids. On filing or scraping cerium with a knife, the filings or scrapings will take fire. It can be prepared by fusion of the anhydrous chloride, but not by direct reduction of its oxide by carbon, as a carbide is formed. Lanthanum, praseodymium and neodymium greatly.



resemble it. Cerium fluoride is used in the "flaming-arc" lamp. Kindling temperature, about 165°C.

**Chlorine.**—Atomic weight, 35.46. Gas at ordinary temperatures. It derives its name from its greenish-yellow color. Strongly corrosive to organic tissues as well as to most metals. A violent poison. Liquefies readily. It is much used in commerce as a bleaching material, for which it is derived by the WELDON process (*q.v.*), or by electrolysis of sodium chloride solutions (CASTNER-KELLNER, GIBBS process, etc.). The hypochlorites form the basis for many disinfectants; the chlorates form the basis of many modern explosives.

**Chromium.**—A bright gray, very lustrous, very hard crystalline metal. Atomic weight, 52.0; sp. gr., 6-7. It oxidizes slowly in cold air, readily on heating. Does not burn so readily as iron on heating in oxygen. Combines readily with the halogens, sulphur, silicon and carbon.

Chrome-iron ore can be directly smelted with carbon to give ferrochrome. To obtain pure chromium the chrome-iron ore is roasted with sodium carbonate or sodium carbonate and lime. The mass should not be fused. From this sintered mass sodium-chromate can be leached out. If  $H_2SO_4$  is added to sodium-chromate solutions the bichromate is produced. Sodium bichromate can be reduced with sulphur to give chromous anhydride, which can then be reduced with carbon or with aluminum. In the carbon reduction the metal is not fused, but remains as a powder. Chromium alloys readily with iron, manganese, cobalt and tungsten; with other metals only with difficulty. It can also be prepared by aluminum reduction.

**Cobalt.**—Atomic weight, 58.97; trivalent; sp. gr. 8.79-8.93. A silver-white metal, melts at 1610°C. if pure. The commercial metal usually melts about 1480°C. Yield point, 31,200-65,600 lb. per sq. in. Specific heat, 0.1056 (15°-100°). This is the most magnetic element except iron. Exceeds iron both in hardness and tenacity. May be turned with ordinary lathe tools. Brinnell hardness, chilled from melting point, 90.8; annealed from 250°C., 77.3. Cobalt may be separated from nickel when both are in solution by precipitation with milk of lime or with calcium hypochlorite; the cobalt comes down first. Cobalt at room temperature has a hexagonal, close-packed configuration; at high temperatures the structure is face-centered cubic. The transformation occurs between 400 and 450°C. In the iron-cobalt series of alloys those containing 50 to 67 atomic per cent. of cobalt are unique in that the alloy has an electrical resistivity lower than that of either component metal.

**Columbium.**—Atomic weight, 93.5; sp. gr., 8.3; m.p. about 1950°C. The metal is silvery white and may be coated with iridescent, colored oxides by electrolysis. It is very inert, but soluble in a mixture of nitric and hydrofluoric acids. It absorbs gases readily, is very ductile, and is easily worked cold. Columbium is always found associated with tantalum.

It is claimed by George W. Sears that if an ore of tantalum and columbium is fused with sodium pyrosulphate at from 835° to 875°C., the columbium is converted to a form soluble in strong  $\text{H}_2\text{SO}_4$ , while all the tantalum remains in insoluble form.

**Copper.**—Atomic weight, 63.57. The only red metal. Bivalent. Tough; ductile. The best conductor of electricity (except perhaps silver); the third best conductor of heat. Recovery of copper is chiefly by smelting sulphide ores to give a copper-iron sulphide, the earthy materials forming a fusible slag, then blowing air through the sulphide (known as matte) getting metallic copper, sulphur dioxide, and ferrous oxide, which is slagged by addition of silica. This smelting may be done in either blast or reverberatory furnaces. The metal from the desulphurizing operation (converting) is then furnace refined if non-argentiferous, or by electrolysis if silver-bearing. Copper is also produced by direct reduction of oxide and carbonate or roasted sulphides to metal (black copper) and by wet processes, as at Rio Tinto, Wallaroo, Chuquicamata, etc. A preliminary concentration of the copper minerals in an ore by gravity or flotation is also much practised.

**Fluorine.**—A slightly greenish-yellow gas, occurring in nature chiefly in fluorspar. One of the most active of the elements. Combines with hydrogen even in the dark. It is the only element except those of the argon group which will not combine with oxygen. It attacks all metals except platinum and gold, and decomposes most organic compounds. It is used to etch on glass (as  $\text{HF}$ ), as an electrolyte in lead refining (as  $\text{H}_2\text{SiF}_6$ ), as a valuable flux (as  $\text{CaF}_2$ ), and in the manufacture of aluminium (as  $\text{Na}_3\text{AlF}_6$ ). Fluorine can be generated by the electrolysis of molten acid potassium fluoride ( $\text{HKF}_2$ ) using graphite for anode and cathode and a diaphragm of copper to separate the  $\text{H}_2$  and  $\text{F}_2$ . The operating temperature is about 240°C. The MATHERS' cell uses the same electrolyte, but the cell, serving as cathode, is made of magnesium. It operates at 250°C.

**Gallium.**—A rare metal which, although tough, may be cut with a knife. With aluminum it forms a liquid alloy which will decompose water.

**Gallium and Germanium Extraction from Zinc Oxide.**<sup>1</sup>—The method for the extraction of germanium consists in dissolving the oxide in hydrochloric acid, adding a suitable amount of potassium chlorate and distilling between 121° and 135°C. between which temperatures the chloride of germanium passes into the distillate. The sulphide of germanium is then precipitated by hydrogen sulphide.

The residue in the flask contained the gallium. After the greater part of the lead present had settled out as the chloride the lead was decanted and treated with ammonium hydroxide until a slight permanent precipitate was formed. The whole was then digested with zinc for several hours at the boiling point, all evaporated water being replaced. The precipitation

<sup>1</sup> H. C. Fogg and C. JAMES, *Journ. Am. Chem. Soc.*, June, 1919.

of the gallium was said to be complete when some of the supernatant liquid gave a precipitate of basic chloride upon the addition of water. The metals and basic salts were removed by filtration. The precipitates containing gallium were dissolved in hydrochloric acid with a little potassium chlorate, the oxides of chlorine boiled off and the solution allowed to stand. Any lead chloride was filtered off and the filtrate saturated with hydrogen sulphide and the precipitate filtered off. After removing the hydrogen sulphide from the filtrate it was again treated with ammonium hydroxide and digested with zinc as described above. The precipitates thus formed, rich in gallium, were again dissolved and the solution saturated with hydrogen sulphide. After removing the hydrogen sulphide, the filtrate was treated with ammonium chloride, made alkaline to litmus with ammonium hydroxide and boiled until just acid. The precipitate consisted of gallium, aluminum and iron. These hydroxides were dissolved in hydrochloric acid, the solution nearly neutralized with sodium hydroxide, some formic acid added and a little sodium formate. The precipitate containing the gallium, aluminum, and traces of cadmium and tin was treated with hydrogen sulphide and some 1 per cent. hydrochloric acid to remove the cadmium and tin. The gallium and aluminum in the filtrate were precipitated by ammonium hydroxide, and after dissolving in hydrochloric acid, and treating with an excess of sodium hydroxide, the gallium was precipitated as the metal by electrolyzing with a current of 1.5 amp.

**Gold.**—Atomic weight, 197.2 ( $O = 16$ ); trivalent; sp. gr., 19.29–19.37; the only yellow metal; most malleable and ductile of all metals; softer than silver, harder than tin; tenacity, about 14,000 lb. per sq. in. with 30.8 elongation. Melts at  $1063^{\circ}\text{C}$ ., begins to volatilize at  $1100^{\circ}\text{C}$ ., and volatilizes four times as fast at  $1250^{\circ}\text{C}$ . Electric conductivity 76.7 ( $\text{Ag} = 100$ ). One oz. of gold leaf covers about 160 sq. ft. U. S. gold coin is 900 parts gold, 100 parts copper. Gold is recovered either by purely mechanical concentration (panning, etc.), by amalgamation, by dissolving it in chemical reagents (chlorination, cyanidation) or by recovering it in a fusion process with copper or lead. Has very small tendency to absorb gases when molten, but absorbs about 0.7 per cent.  $\text{H}$ ,  $\text{CO}$ , and other electropositive gases when cold, if it is finely divided. It is dissolved by no one acid except nitrous, but is dissolved by any mixture (such as *aqua regia*) generating chlorine and bromine. Except in the thiosulphate, it does not play the part of base to oxy-acids.

Gold possesses the lowest solution tension of any metal. It may be precipitated from its solution by even the weakest reducing agents, such as  $\text{H}$ ,  $\text{P}$ ,  $\text{As}$ ,  $\text{Sb}$ ,  $\text{C}$ , by nearly all metals (except from cyanide solution, from which it can be separated only by zinc and metals more electropositive than zinc), by metallic sulphides, by protosalts of iron, tin, etc., by hypophosphites, sulphites,  $\text{SO}_2$ , the lower oxides of nitrogen, arsenic, oxalic acid, etc.

**Hafnium.**—Discovered in 1922 by G. HEVESY. Always occurs in minerals containing zirconium. Atomic number, 72; atomic weight, 178.6. Found in the United States in cyrtolite near Bedford, Westchester County, N. Y., and at Rockport, Mass. Hafnium is highly radioactive. All data published previous to 1922 regarding zirconium and its compounds is really data as to mixtures of zirconium and hafnium. Its chemical reactions are identical with those of zirconium, from which it is separated by fractional crystallization of the ammonium-zirconium and ammonium-hafnium hexa-fluorides.

**Helium.**—First discovered by spectroscopic observation of the sun. One of the rarest of the elements on the earth's surface. Found in some uranium minerals, is given off by the gases of certain springs, and is found in the air in the proportion of 0.0005 per cent. It is absolutely inactive. Atomic weight, 4.00.

**Iodine.**—Atomic weight, 126.93. Occurs at ordinary temperatures as beautiful violet to black crystals. It is largely used in the aniline color industry, in making iodoform and in potassium iodides in photography and medicine. The chief sources of iodine are the mother liquors of the Chilean nitrate industry and the ashes of sea weeds. It is readily precipitated from iodates thus:



**Iridium** is insoluble in every acid, differs from platinum in not being soluble in *aqua regia*, although when the iridium is very finely divided it is attacked by this reagent. Fusion with acid potassium sulphate oxidizes it but does not dissolve it (distinction from ruthenium). It also oxidizes to the trioxide,  $\text{Ir}_2\text{O}_3$  when heated with fused sodium nitrate and hydroxide, or with hydroxide alone in the presence of air, but the residue is but slightly soluble in water. Iridium may be distinguished from platinum by suspending the precipitate produced with caustic alkalis in a solution of potassium nitrite and the solution saturated with  $\text{SO}_2$  and boiled, renewing the water so long as  $\text{SO}_2$  is given off, all of the iridium is converted to an insoluble brownish-green basic iridic sulphite. Iridic salts are reduced by alcohol in alkaline solutions to iridous compounds soluble in hydrochloric acid. For a method of decomposing osmiridium, see "osmium," p. 315.

**Iron.**—A white metal of atomic weight, 55.84. Forms two series of compounds, ferric (trivalent) and ferrous (bivalent) which pass from one form to the other by very gentle reduction or oxidation.

Iron is the most magnetic of the metals. It alloys readily with most of the earth metals, only slightly with Pb and Cu. In the presence of Si, iron will dissolve more Cu than otherwise, that is cuprosilicon is dissolved more readily than is pure Cu. Fe alloys readily with C, Si, P, S and O.

**Ferrosilicon.**—Maximum tensile strength at 4.5 per cent. Si; tensile, 93,000 lb. per sq. in.; 74,000 lb. yield point; sharp.

drop from 4.5 per cent. Si to 5 per cent. Si, where ultimate strength and yield point coincide at 43,000 lb.

**Ferrosilicon.**—Resistivity rises from 0 per cent. Si (10 microhms per cc.) to about  $8\frac{3}{4}$  per cent. Si (105 microhms per cc.) then drops to 14.5 per cent. Si (40 microhms per cc.) then steadily rises. There is a maximum resistance to corrosion coinciding with the minimum resistance at 14.5 per cent. S (M. G. BORSON, *Trans. A.I.M.E.*).

**Electrolytic Iron.**—Ultimate tensile, 35,000 lb. per sq. in.; yield point, 16,000 lb.

**Iron Metallurgy.**—Iron is produced by a reducing smelting after concentration or roasting or both. The slag, usually known as cinder, differs from that of the lead and copper metallurgists in being a calcium-aluminum silicate. The use of preheated blast, often previously dried, is also at variance with non-ferrous practice. The iron produced always contains Si, C, P, S, etc. Indeed most of the usefulness of iron depends on its carbon content; so a list is herewith appended of the carbides of iron and their modification, with the names applied to them by the iron metallurgists.

**Ferrite.**—Chemically pure iron:  $\alpha$ -iron, magnetic and free from C, passes at  $780^{\circ}\text{C}$ . into  $\beta$ -iron, which is non-magnetic and practically incapable of dissolving C. Above  $880^{\circ}\text{C}$ .  $\beta$ -iron passes into  $\gamma$ -iron which is non-magnetic and capable of dissolving C or  $\text{Fe}_3\text{C}$ .

**Cementite.**—Iron carbide,  $\text{Fe}_3\text{C}$ .

**Austenite and Martensite.**—Solid solutions of  $\text{Fe}_3\text{C}$  in  $\gamma$ -iron.

**Troosite.**—Colloidal solution of  $\text{Fe}_3\text{C}$  in Fe.

**Sorbite.**—Mixtures of Fe,  $\text{Fe}_3\text{C}$  and solid solutions of  $\text{Fe}_3\text{C}$  in Fe.

**Pearlite.**—The eutectic between ferrite (Fe) and cementite ( $\text{Fe}_3\text{C}$ ). It corresponds to 0.9 per cent. C, or ( $\text{Fe}_3\text{C} + 20\text{Fe}$ ).

**Temper Carbon.**—Non-graphitic carbon which separates from white iron by keeping it for a long time at a temperature near  $1000^{\circ}\text{C}$ ., during which time the finely divided cementite changes into a mixture of ferrite, pearlite and temper carbon. Temper carbon is more readily oxidizable than graphite or carbide carbon.

**Forgeable Iron.**—The saturation point of  $\text{Fe}_3\text{C}$  in Fe is reached at 2 per cent. C ( $2\text{Fe}_3\text{C} + 15\text{Fe}$ ). Anything up to this point may be regarded as forgeable iron.

**Steel Hardening.**—This is explained by assuming a transformation of pearlite to martensite, and the maintenance of this solid solution by quenching.

**Malleablizing.**—By exposing white iron for a long time to about  $1000^{\circ}\text{C}$ ., the dissolved  $\text{Fe}_3\text{C}$  is converted into Fe and C, but the carbon is not present as graphite, but in an easily oxidized state. It is then oxidized by  $\text{Fe}_2\text{O}_3$  or  $\text{FeCO}_3$ .

White iron is a supercooled solution and may be regarded as a metastable system between  $\text{Fe}_3\text{C}$  and Fe, in which the reaction  $\text{Fe}_3\text{C} = 3\text{Fe} + \text{C}$  has not been allowed to take place.

Gray iron is a stable system  $\text{Fe}-\text{Fe}_3\text{C}-\text{C}$ . It has had time, at the different temperatures and concentrations to reach a more or less complete state of equilibrium. During the cooling some of the  $\text{Fe}_3\text{C}$  has decomposed into Fe and C, the latter being found as graphite. See also BESSEMER (p. 608), THOMAS-GILCHRIST (p. 612) and SIEMENS-MARTIN (p. 612).

**Krypton.**—Present in the proportion of 1:1,000,000 in air. Inert. Has a characteristic spectrum, noticed especially in the Aurora Borealis. Atomic weight, 82.9. Discovered by Ramsay in the last liquid from the evaporation of liquid air.

**Lanthanum.**—Greatly resembles cerium, which see. It occurs chiefly in monazite sand.

**Lead.**—Atomic weight, 207.2; tetravalent; sp. gr., 11.35–11.37, when molten, 10.37–10.65; a dull gray metal, malleable but not ductile; tenacity the lowest of any common metal. Melts at 327.5°C.; electric conductivity 10.7 with silver 100. Heaviest of all base metals. Boils at 1525°C. Has a great affinity for all the noble metals and is often used as a carrier in their extractions.

Lead is obtained from its ores by roast-reaction process ( $2\text{PbO} + \text{PbS} = 3\text{Pb} + \text{SO}_2$  or  $\text{PbSO}_4 + 2\text{PbS} = 3\text{Pb} + 3\text{SO}_2$ ); by the so-called precipitation process ( $\text{PbS} + \text{Fe} = \text{Pb} + \text{FeS}$ ); or by reduction with carbon of oxide and carbonate ores or previously roasted sulphides. The argentiferous lead is refined by either the PARKES, PATTINSON or BETTS processes (*q.v.*, pp. 611, 611, 608).

**Lithium.**—Atomic weight, 6.94; monovalent; sp. gr., 0.5936. A soft silver-white metal. Melts at 186°C.; vaporizes at about 500°C. Below 200°C. may be melted in the air; above that, bursts into flame. Decomposes water at ordinary temperatures. It is the lightest known metal.

**Magnesium.**—Atomic weight, 24.32; bivalent; sp. gr., 1.75. A white lustrous metal of fibrous crystalline structure. Malleable and ductile, not tough. Melts at 651°C.; boils at about 1120°C. Large pieces oxidize superficially. In powder it burns readily. Combines readily with nitrogen at elevated temperatures. Is a good deoxidizer. Lightest of metals in common use. When powdered, it is highly combustible, burning with a vivid light.

**Electrolytic Magnesium.**—The direct production of magnesium from magnesium oxide can be carried out using an electrolyte of fused magnesium fluoride carrying small quantities of calcium, barium, and sodium fluorides. Using 10 per cent. of  $\text{MgO}$  in the bath, the current density should be about 10 amp. per sq. cm. at the cathode (HARVEY Process).

**Manganese.**—Atomic weight, 54.93; usually bivalent, may be heptavalent; sp. gr. given by various authorities at from 7.39 to 8.30. Silvery, lustrous, hard, brittle, smooth fracture. Melting point, 1260°C. Volatilizes considerably even at the melting point. Boils about 1900°C. Cannot be reduced by carbon to pure metal, as some  $\text{Mn}_3\text{C}$  is always formed, but can be produced in comparative purity by reduction of  $\text{Mn}_2\text{O}_3$ .

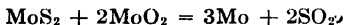
by aluminum. Is used commercially mainly as ferromanganese, which is formed by direct reduction of manganese and iron ores.

**Mercury.**—Atomic weight, 200.6; bivalent; sp. gr., when fluid at 0°C., 13.59; solid at -40°C., 14.19. Silver white with bluish tinge. Melts at -38.87°C. Contracts on solidification, forming a white, very ductile, very malleable mass, which can be cut with a knife. Specific heat from -78° to -40°C. is 0.0247; of the fluid metal, 0 to 100°C., 0.0333. Electric conductivity at 22.8°C. is 1.63. Heat conductivity, 67.7 (Ag = 100). Boils at 357°C. Amalgamates readily with gold, silver, zinc, tin, cadmium, lead and bismuth; with copper when finely divided; with arsenic, antimony and platinum with difficulty; with iron, nickel and cobalt not at all directly. Is obtained by smelting the ores and catching the flue dust, in which the mercury condenses.

**Molybdenum.**—Atomic weight, 96.0; quadrivalent; sp. gr., 8.62-9.01. A white, extremely lustrous, very hard metal. Acids scarcely affect it, except nitric, which converts it to molybdic oxide or acid. The sulphides readily form thio-salts with alkaline sulphides. Remains unchanged in air at ordinary temperatures, but oxidizes slowly when heated to redness. Used in high-speed steels, where it exercises about twice the influence that tungsten does. It cannot be produced pure by direct reduction of the oxide by carbon. Melts at 2620°C.

The reduction test for molybdenum is as follows: A small quantity of molybdate or wulfenite, in a powdered state, together with a scrap of paper, should be placed in a test-tube with a few drops of water and an equal quantity of concentrated sulphuric acid. The tube and its contents should then be heated until the acid fumes begin to come over. After allowing the tube to cool, water should be added, a drop at a time. The addition of the first drops gives rise to a deep blue color, which disappears as more water is added.

For the preparation of molybdenum the ore must be roasted at less than 600°C. to less than 0.5 per cent. S. At even the prescribed temperature there is some sintering, so the roasted ore is again ground and then leached with hot water and ammonia. The filtered solution is then purified. Iron is first removed by treatment with H<sub>2</sub>O<sub>2</sub> near the boiling point. Copper is then removed by precipitation in the cold with ammonium sulphide. Calcium is precipitated with ammonium oxalate. Ammonium molybdate is then removed by crystallization (EDWIN K. JENCKES, *Trans. A.E.C.S.*, 1927). J. ESCARD (*Rev. Gen. de l'Electricité*, Sept. 14, 1918) states that molybdenum may be prepared by heating together a mixture of molybdite and molybdenum oxide in an electric furnace:



1

The destruction of molybdenum ribbons used as resistors in electric furnaces is due chiefly to chemical reaction with

materials present in heating tubing, insulation, or gases in the furnace. Of those materials most likely to be there, silica and carbon are the most destructive. For the best working conditions of such furnaces it is recommended that:

(1) Both heating tubing and insulation should be of calcined pure alumina, mixed with aluminum hydroxide as binder and fired at 1500°C.

(2) The first heating of a new furnace should be carried out under high hydrogen pressure, which may be later reduced.

(3) If the material used for heating tubing or insulation contains carbon, oxides of a high degree of oxidation should be added, so that they may react with it, the products of the reaction to be removed by evacuation.

(4) The molybdenum ribbon may be coated with molybdenum oxides having a low degree of oxidation to protect it from forming oxides or carbides (HENRY J. MILLER and MARCELLA LINDEMAN, *Trans. A.I.M.E.*, 1927).

**Monel Metal.**—An alloy of copper, nickel, and iron, Cu 33.0 per cent.; Fe, 6.5 per cent.; Ni, 60.0 per cent.; Al, 0.5 per cent. Specific gravity 8.80; m.p., 1316°C., coefficient of thermal expansion, 25° to 300°, 0.000015; specific heat 20° to 400°C., 0.127; electrical resistivity, ohm-mil-ft, 256; coefficient of electrical resistivity per deg. C., 0.0019; yield point, hot-drawn rods, 45,000 lb. per sq. in.; ultimate tensile, 85,000; yield point, cold-rolled sheets, 100,000; ultimate tensile, 130,000 lb. per sq. in.

**Neodymium.**—Greatly resembles cerium, which see.

**Nickel.**—Atomic weight, 58.69; sp. gr., cast, 8.35, rolled or hammered. 8.6 to 8.9; is very hard; can be rolled to sheets not over 0.0008 in. thick and drawn into a wire 0.0004 in diameter. According to SHAKELL the tenacity is 42.4 tons per sq. in. for annealed wrought nickel. It melts at 1452°C. when pure; the melting point is considerably lowered by carbon. Nickel is attracted by a magnet (Ni:Fe::1:1.54), but it loses this power at 340°C. Its electric conductivity is 12.9 (Ag = 100). The metallurgy of nickel somewhat resembles the fire metallurgy of copper, in that the ores are smelted, following either wet concentration or roasting, or both, and the nickel-copper matte is bessemerized, but the converting process is not carried so far as in copper. In constitution nickel matte seems to vary, as the nickel content increases, from (Ni<sub>2</sub>S and FeS) to (Ni<sub>3</sub>S<sub>2</sub> and FeS) to pure Ni<sub>3</sub>S<sub>2</sub> or even a solution of Ni in Ni<sub>3</sub>S<sub>2</sub>. Nickel speiss consists of Ni<sub>3</sub>As<sub>2</sub>, NiAs and probably Ni<sub>5</sub>As<sub>2</sub>. The partly bessemerized mattes and speisses are then given the so-called "top and bottom smelting"—a reducing fusion with sodium sulphate. The product of this fusion consists of a layer of slag, a Cu-Fe-Na matte, and a Ni-Fe matte at the bottom. By repeated top and bottom smeltings a copper matte practically free from nickel and a nickel matte practically free from copper are obtained.

The nickel matte is then worked up by one of numerous wet processes. A part of the present Ni-Cu matte from the



Canadian Copper Co.'s works is worked down into metal (the so-called monel metal) without separation of the nickel, copper and iron. The electrolytic baths are probably neutral sulphate containing considerable amounts of borate. An interesting method of nickel recovery from products in which the nickel occurs as oxide, oxide ores or roasted sulphides is the Mond process. A reducing roast is given the ores in retorts heated to 300°C. with gases containing H, whereby the nickel oxide is reduced to sponge Ni. The reduced nickel is then exposed to gas containing CO at 100°C. and 15 atmospheres pressure. Volatile nickel carbonyl is formed. This is stable at 50°C. at 2 atmospheres pressure; at 100° at 15 atmospheres; at 180° at 30 atmospheres; and at 250° at 100 atmospheres. The vapors of  $\text{Ni}(\text{CO})_4$  escaping from the vessels under pressure can be dissociated by simply lowering the pressure. The electrolyte formerly used by the Balbach works was said by ULKE to be a hot nickel sulphite, the current density to be 15 amp. per sq. ft. and a tank voltage of 1.7-1.8 volts.

**Osmium.**—The heaviest of all metals; sp. gr. 22.48; atomic weight, 190.9. Osmium is volatilized in, but not melted by the oxyhydrogen blowpipe. When strongly heated in contact with air the finely divided metal burns to osmic anhydride,  $\text{OsO}_4$  (usually known as osmic acid). The oxide is remarkable for its peculiar, exceedingly irritating and offensive odor. It is injurious to the eyes and is extremely poisonous. This oxide is soluble in water, giving a neutral solution, from which it is precipitated by nearly all metals, even silver, as a black precipitate. Fuming nitric acid or *aqua regia* also oxidizes osmium to  $\text{OsO}_4$ . When intensely ignited, osmium is rendered insoluble in acid, and must be fused with niter and distilled with  $\text{HNO}_3$ , when  $\text{OsO}_4$  will distill over. All compounds of osmium yield the metal when ignited in hydrogen. Osmiridium may be attacked by mixing it with common salt or potassium chloride and exposing it in a glass or porcelain tube to a current of moist chlorine gas. Osmic acid is formed, which volatilizes below 212°C. and can be condensed and fixed by passing the fume into an alkaline solution. Iridium remains behind in the tube as a double chloride,  $2\text{KCl} \cdot \text{IrCl}_4$ .

**Palladium** is the most fusible of the so-called platinum metals. The metal oxidizes when heated in air. It absorbs hydrogen to a large extent. A solution of iodine produces a black stain on palladium, but has no effect on platinum. The best solvent for palladium is *aqua regia*. It is sparingly soluble in pure nitric acid, but dissolves more readily in fuming nitric acid, forming palladious nitrate,  $\text{Pd}(\text{NO}_3)_2$ . All palladium compounds decompose on ignition. Melts at 1555°C.

**Phosphorus.**—Found in nature chiefly as the tri-basic calcium phosphate. To produce phosphorus the calcium phosphate is treated with sulphuric acid in lead-line tanks. This converts the tricalcium into monocalcium phosphate. The clear solution is then drawn off and the precipitate thoroughly washed. The solution and washings are evaporated

to 45°Bé. and about 25 per cent. of coke or charcoal added and the pasty mass dried in iron pans. The dry mixture is then distilled in cast-iron retorts and the fumes passed into a condenser containing water, under which the phosphorus collects. Phosphorus melts at 44°C. and distills at 287°C. It must be kept under water.

**Platinum.**—Atomic weight, 195.3; tetravalent; sp. gr., cast, 21.5; a white metal of a grayish tinge; is very malleable and ductile; harder than copper, silver and gold; tenacity about 23,000 lb. per sq. in. (DEVILLE and DEBRAY); electric conductivity 13.4 at 0°C. ( $\text{Ag} = 100$ ); melts at 1755°C., but is sensibly volatile at 1300°C. Is mainly recovered from alluvial deposits, but is also got in WOHLWILL's process of electrolytic gold refining, where it remains in the solution. It is affected by fused alkaline hydroxides, phosphorus, cyanides, sulphides and halogens. Platinum is not acted upon either by pure hydrochloric, nitric or sulphuric acid. It dissolves in *aqua regia* and other mixtures, evolving chlorine, but less readily than gold, so that gold which has been fused to platinum can be dissolved by dilute *aqua regia* at moderate temperatures without injuring the platinum. When alloyed with silver, lead and some other metals it is dissolved (see tables on pp. 394, 395).

**Potassium.**—Atomic weight, 39.1; monovalent; sp. gr., 0.865. A bluish-white metal, softer than sodium; fuses at 62.3°C., vaporizes about 667°C. The vapor is greenish. Like sodium in its reactions (*q.v.*). However, there is an explosive material left in the retorts when potassium carbonate is reduced by carbon, and the process is dangerous. It is found in greatest abundance in the salt deposits of Stassfurt, Germany.

**Praeseodymium.**—The element occurs chiefly in monazite sands. The metal is silvery white, corrodes rapidly in air, is slightly attacked by hot water; vigorously by mineral acids and halogens. The kindling temperature is 290°C. The metal is not pyrophoric. BRINELL hardness (500 kg. wt.) is 25; sp. gr. 6.6; m.p. 940°C. Greatly resembles neodymium.

**Rhodium** is found in the insoluble residue resulting from the treatment of crude platinum with *aqua regia*. It is, when pure and in a compact state, not acted upon by even *aqua regia*, but when alloyed with lead, copper or bismuth in certain proportions it dissolves in it. When alloyed with gold or silver it does not dissolve. It is oxidized by air at a red heat, or by fusion with potassium hydroxide and niter. It is converted by fusion with acid potassium sulphate into the soluble potassium rhodic sulphate  $\text{K}_3\text{Rh}_2(\text{SO}_4)_6$ . Mixed with sodium chloride and ignited in chlorine it forms the easily soluble  $3\text{NaCl} \cdot \text{RhCl}_3 \cdot \text{H}_2\text{O}$ . Rhodium is distinguished from the other platinum metals by its insolubility in *aqua regia*, its solubility in fused  $\text{H}_2\text{SO}_4$ , and the formation of a brown precipitate on adding  $\text{KOH}$  and alcohol to rhodium-chloride solution.

**Ruthenium** is found in the insoluble residue resulting from the treatment of platinum ore with *aqua regia*. It is a grayish-

white metal, closely resembling iridium and very difficultly soluble. When heated in air it becomes covered with bluish-black ruthenic oxide,  $\text{Ru}_2\text{O}_3$ . When pure it is unacted on by acid, and is scarcely acted on by acid potassium sulphate. It is attacked by fusion with potassium hydrate and niter, or potassium chlorate and is converted into  $\text{K}_2\text{RuO}_4$ , a dark-green mass, soluble in water to an orange-colored fluid which stains the skin black. Ruthenium is rendered soluble by ignition with potassium chloride in a current of chlorine, being converted to  $2\text{KCl} \cdot \text{RuCl}_4$ .

**Selenium.**—An element originally recovered from the dust chambers and mud of the lead chambers of sulphuric-acid plants. The classic process is to leach the mud with concentrated potassium cyanide, forming  $\text{KCNSe}$ , and then precipitating the Se by adding hydrochloric acid. My own process, by which most of the commercial selenium was made between the years 1906 and 1919, applicable to all non-oxidized residues, is to oxidize seleniferous flue dusts with  $\text{HCl}$  and  $\text{NaClO}_3$ , then after all the free chlorine is gone, precipitate the metal with sulphur dioxide. The precipitate is then washed and dried. The bulk of the present production comes from the oxidized dusts from roasting copper slimes, which are leached and the Se reduced with  $\text{SO}_2$ , or from soda slags. These are crushed and leached with hot water and the solution brought to neutrality. The tellurium is precipitated and the tellurium-free solution is then acidified with  $\text{HCl}$  and the Se precipitated. Selenium occurs in several amorphous modifications, some soluble in  $\text{CS}_2$ , some insoluble; in certain crystalline forms when precipitated from solution; in a vitreous form when melted and cooled quickly; and a so-called metallic form when melted and cooled slowly. This metallic modification has the remarkable property of altering its electric conductivity when illuminated. The vitreous modification passes over into the metallic when heated for some time above  $180^\circ\text{F}$ . There is a considerable evolution of heat during the change.

**Silver.**—Atomic weight, 107.88; monovalent; sp. gr., cast 10.50, minted 10.57. Melts at  $960.5^\circ\text{C}$ ., boils at  $1955^\circ\text{C}$ . It is the whitest of metals, harder than gold, softer than copper, more malleable and ductile than any metal except gold, the best conductor of heat and electricity of known substances. (Some authorities state that gold is the best conductor of heat and copper of electricity. In any case the difference is slight.) It volatilizes at high temperatures, yielding a green vapor. In the molten state it has the property of absorbing twenty-two times its volume of oxygen, which is given out on cooling, causing the so-called spitting of silver. This occurs only with the pure metal. Small quantities of copper, bismuth and zinc entirely prevent it, as does also an inert cover. Arsenic, antimony, bismuth and lead render silver brittle. It is recovered by amalgamation, by chemical processes (Augustin, Ziehvogel, Kiss, Russell, Patera, Patio, Cyanide, etc.) and from the impure bullion from lead or copper smelting. From

lead it is recovered by the PATTINSON, PARKS and BETTS processes (*q.v.*) and from copper by electrolytic parting. In both these cases it contains gold, which is then recovered either by dissolving the silver by sulphuric or nitric acid, or by electrolytically refining the silver by the MORBIUS or THUM process. The auriferous silver bullion is known as doré. Silver does not oxidize in air, even if heated, but is easily attacked by sulphur and its compounds. It is attacked by nitric acid, and by hot sulphuric, scarcely at all by hydrochloric nor by the halogens and not at all by fused alkaline hydroxides.

**Sodium.**—Atomic weight, 23.00; monovalent, sp. gr., 0.974. A soft silvery-white metal, which may be kneaded at ordinary temperatures. Melts at  $97.5^{\circ}\text{C}$ .; vaporizes at about  $742^{\circ}\text{C}$ . Dissolves in anhydrous ammonia. Decomposes water at ordinary temperatures, and must be kept under oil. Burns in dry air to the peroxide,  $\text{Na}_2\text{O}_2$ . Practically all sodium compounds are soluble. Can be reduced from the carbonate by carbon.

**Strontium.**—A soft white metal. Found chiefly in nature as carbonate and sulphate. Is used in the manufacture of fireworks for red fire, and in the refining of sugar.

**Tantalum.**—Atomic weight, 181.5. A rare element usually occurring with columbium. It is not attacked by hydrochloric or nitric acids or by *aqua regia*, either hot or cold. It is slowly attacked by boiling, concentrated sulphuric acid. Solutions of caustic alkalies do not attack the metal easily. Hydrofluoric acid will attack it. A mixture of hydrofluoric and nitric acids will attack the metal with avidity, causing it to go into solution as tantalum fluoride.

If tantalum is heated in the air, the surface becomes blue at a temperature of about  $400^{\circ}\text{C}$ ., and at a somewhat higher temperature, nearly black. Above a dull-red heat the white oxide is produced and the metal gradually burns. This metal combines with avidity with hydrogen, oxygen, or nitrogen, and most common gases. It will take up 740 times its own volume of hydrogen, producing a very coarse-grained, brittle product. Can be used for electrolytic cathodes, but not as anodes, as it oxidizes under anodic action.

**Tellurium.**—Atomic weight, 127.5. Melts,  $452^{\circ}\text{C}$ . A metal much like selenium. Occurs usually as gold or silver telluride. Can be separated from selenium by a fractional separation with  $\text{SO}_2$ , for selenium precipitates from concentrated hydrochloric-acid solutions with  $\text{SO}_2$ , while tellurium does not, or by taking a mixture of finely divided precipitates, leaching with concentrated cyanide solutions at ordinary temperatures, heating the solution, and filtering hot. The selenium is dissolved. Can also be separated electrolytically, using impure tellurium anodes, lead cathodes, and an electrolyte of tellurium dioxide dissolved in a mixture of sulphuric and hydrofluoric acids.

**Tin.**—Atomic weight, 118.7; quadrivalent; sp. gr., cast 7.287, rolled 7.30, tetragonal form (electrolytically deposited)

7.25, rhombic 6.55, ordinary commercial about, 7.5, friable modification (due to tin pest) 5.8; melts at  $231.9^{\circ}\text{C}.$ ; boils at  $1500^{\circ}\text{C}.$ ; specific heat, 0.0562; coefficient of linear expansion, 0.00223; heat conductivity, 15.2 ( $\text{Ag} = 100$ ). Most malleable at about  $100^{\circ}\text{C}.$ , most brittle at about  $200^{\circ}\text{C}.$  Rolls to sheets not over  $\frac{1}{5000}$  inch thick. Tensile strength of very pure bars 2420 lb. per sq. in. (H. Louis), of hammered 2540 lb. per sq. in., commercial about 4600 lb. per sq. in., tin foil about 5980 lb. per sq. in. Breaks down at low temperatures to a gray granular powder (tin pest); the change commences at  $18^{\circ}\text{C}.$ , and is most rapid at  $-48^{\circ}\text{C}.$  Boils at  $1500^{\circ}$  to  $1600^{\circ}\text{C}.$  if heated out of access of air. It is but little affected by air and moisture at ordinary temperature. Electric conductivity, 14.4 ( $\text{Ag} = 100$ ). Decreases in volume by 6.75 per cent. on solidification. Acted on by  $\text{Cl}$ ,  $\text{HCl}$ ,  $\text{H}_2\text{SO}_4$  and  $\text{HNO}_3$ , but is only oxidized by latter and does not form nitrates. Ores are usually concentrated, roasted if required and smelted in shaft or reverberatory furnaces, and refined by fire processes. Analyses of English tin show (H. Louis, "Metallurgy of Tin"): Sn, 98.64–99.76; Fe, tr–0.13; Pb, 0–0.20; Cu, tr–1.16. Tin from Pulo Brani showed, Sn, 99.76; Sb, 0.07; Pb, 0.02; Fe, 0.14; Cu, As, none. Is perceptibly volatile at  $1200^{\circ}\text{C}.$  Because of the high specific gravity of tin oxide it is ordinarily concentrated by mechanical means before smelting. The smelting of tin is difficult because it tends, when there is an excess of base in the slag, to enter it as an acid, forming stannites and stannates, while if there is an excess of silica tin enters the slag as a base.

**Tungsten.**—An almost white, very lustrous hard metal. Atomic weight, 184.0; sp. gr., 19.3–20.2. It begins to oxidize only at elevated temperatures in air. It can be reduced by carbon from the oxide. Ductile tungsten is practically insoluble in the common acids, except in a mixture of  $\text{HF}$  and  $\text{HNO}_3$ . Fused nitrates and nitrites attack it. It has the highest melting point of any metal (c.  $3350^{\circ}\text{C}.$ ); it is paramagnetic, and its wire can be drawn to smaller sizes than can wire of any other metal. The chief commercially important forms are sodium tungstate, largely used for fireproofing and as a mordant, and tungsten as a constituent of high-speed steels. Tungsten may be prepared as a powder by the reduction of tungstic acid,  $\text{H}_2\text{WO}_4$ , tungstic acid,  $\text{WO}_3$ , and ammonium paratungstate,  $(\text{NH}_4)_2\text{W}_{12}\text{O}_{41}$ . The impurities, if tungstic acid is used, should not exceed 0.05 per cent. The density of the tungstic acid powder when placed in a graduate and tapped until no further diminution in volume takes place should be about 0.61 g. per cc. For the preparation of tungstic acid, ores containing excessive quantities of Ca,  $\text{SiO}_2$ , As, and P should be avoided, also those containing Mo, as it is impracticable to separate Mo and W on a commercial scale. In the preparation of tungsten compounds the ores are ground to  $-100$  mesh and then either fused in a reverberatory with sodium carbonate, or digested, with or without pressure, with sodium hydrate.

If fusion has been resorted to, the fusion product is ground to -100 mesh and leached with hot water. Arsenic is precipitated from the solution with copper sulphate. The reaction is quantitative in the cold. The soluble tungstates are then precipitated with calcium-chloride solution. A slurry is made of the precipitated  $\text{CaWO}_4$ , which is treated with an excess of hydrochloric acid, giving tungstic acid and calcium chloride. The crude tungstic acid is leached with aqua ammonia, giving ammonium tungstate. Tungsten can be prepared from tungstic oxide by reduction with carbon. A little  $\text{W}_2\text{C}$  and  $\text{WC}$  is formed in this reduction and dissolved by the metal. Ferrotungsten can also be formed by direct reduction of wolframite or scheelite with iron compounds and powdered quartz or glass. The carbon-free metal can also be produced by the aluminum-reduction process.

A general test for all tungsten ores is carried out as follows:

Strong hydrochloric acid is added to the ore, which is first pulverized to as fine a powder as possible, and part of the tungsten will pass into the solution. Metallic zinc should then be added and the mixture boiled. A fine azure blue denotes the presence of tungsten.

When any ore containing tungsten is fused with sodic carbonate, leached out with hot water and filtered, the tungsten passes into the filtrate. If hydrochloric acid is added the tungsten is precipitated. This precipitate is insoluble in all acids, dissolves readily in ammonia, and is of a fine yellow color. A little of this yellow powder, if added to a bead of salt of phosphorus and treated in a reducing flame, using a blow lamp, gives the fine blue bead characteristic of tungsten.

**Uranium.**—A white lustrous, very hard metal, oxidizing in air only at high temperatures, but igniting in pure oxygen at  $170^\circ$ . Fluorine attacks it at ordinary temperatures, chlorine at  $180^\circ$ , bromine at  $210^\circ$  and iodine at  $260^\circ\text{C}$ . It combines with sulphur at about  $1000^\circ\text{C}$ . to form a black sulphide and with nitrogen at about  $1000^\circ\text{C}$ . to produce a yellow nitride.

**Vanadium.**—Atomic weight, 50.96, sp. gr., 5.50; melts at  $1710^\circ$ . According to BORCHERS the purest metal yet obtained was a gray lustrous powder which ignites readily in the Bunsen flame. It dissolves with great difficulty in hydrochloric or dilute sulphuric acid, but more readily in strong sulphuric acid, in hydrofluoric acid or in nitric. With fused alkali-metal hydroxides it forms vanadates. At elevated temperatures it combines readily with the halogens, sulphur, or even with nitrogen.

**Xenon.**—Occurs in the atmosphere in the proportion of 1:20,000. Heaviest of the rare gases.

**Zinc.**—Atomic weight, 65.37; always bivalent; sp. gr., cast, from 6.861 to 7.149; when rolled, 7.2 to 7.3; when fluid, 6.48 to 6.55. Boils at about  $920^\circ\text{C}$ . Melts at  $419.4^\circ\text{C}$ . Specific heat at  $0^\circ$  to  $100^\circ\text{C}$ ., 0.09555 (REGNAULT); probably 0.1015 from  $100^\circ$  to  $300^\circ\text{C}$ . It burns in air at about  $505^\circ\text{C}$ . Zinc is brittle

at ordinary temperatures, especially if impure, but between 100°C. and 150°C. it becomes malleable and ductile, and may be rolled into sheets and drawn into wire, and retains these properties after cooling. At 205°C. it again becomes so brittle that it may be powdered in a mortar. When cast at a temperature near its melting point it is more malleable than when cast at a higher temperature. In malleability zinc ranks between lead and iron; in ductility between copper and tin. In hardness it stands between copper and tin; more exactly between silver and platinum, being 2.5 on Moh's scale, 6 on TURNER's sclerometer and 1077 on BOTTONE's scale, on which the diamond is 3010. The thermal conductivity is given from 19 (WIEDEMANN) to 64.1 (CALVERT and JOHNSON), silver being 100. Its electrical conductivity is 16.92, mercury at 0°C. being unity. On the basis of silver = 100, BECQUEREL gives its conductivity at 24.06, and WEILLER at 29.90. According to ROBERTS-AUSTEN the coefficient of linear expansion is 0.0000291; CALVERT and JOHNSON give it at 0.00002193 for hammered zinc. The tensile strength of zinc varies from 2700 lb. per sq. in. for cast metal to 17,700 for an annealed rod. Zinc dissolves readily in both acid and alkaline solutions with evolution of hydrogen. A moderate tenor in lead makes zinc malleable and ductile; over 1.5 per cent. Pb is certainly detrimental. Iron up to 0.2 per cent. does not greatly affect the properties of zinc, above that it makes it less fluid, less malleable, less strong, harder and more brittle. Cadmium seems to have no injurious influence except when the spelter or ore is to be used for making zinc oxide. Copper makes zinc harder and more brittle, even if only 0.5 per cent. be present. Tin also makes it harder and more brittle. Other impurities are of minor importance, but silver, thallium, indium, magnesium, aluminum, antimony, arsenic, sulphur, carbon, chlorine and oxygen occur. The metal is produced by smelting the ores in retorts with carbon as a reducing agent, and extraneous fuel to heat them. A fusible slag is not wanted. Sulphide ores must be roasted clean before distillation. The loss of zinc in the smelting process, due to retort absorption, escape through the pores of the retorts, escape of uncondensed zinc through the adapters, through zinc left in the retorts, etc., is very seldom below 10 per cent. and may amount to 25 per cent. Zinc either rolled or cast has no well defined yield point and elastic limit is low. Plasticity high. Ultimate tensile strength of thin-rolled zinc (not over 0.05 in.) is 24,000 lb. per sq. in. Modulus of elasticity 11,500,000 lb. per sq. in.

**Zirconium.**—Atomic weight, 91.0; sp. gr., 6.4; melts about 1700°C., occurs as the natural oxide and as the silicate (zircon). It was used as the incandescing material in the first gas mantles. According to A. L. FIELD (*Trans. A.I.M.E.*, 1923), zirconium when added to molten steel combines chemically with dissolved oxygen, nitrogen, and sulphur, in the order named, and is capable of neutralizing the embrittling effect of phosphorus (not, however, by chemical reaction, apparently).

## DETECTION OF THE METALS

**Aluminum.**—Is precipitated as white gelatinous hydroxide by ammonia. When the oxide is strongly heated on charcoal with cobalt nitrate, a bright-blue mass is obtained. With soda before the blowpipe it swells and forms an infusible compound.

**Antimony.**—When a small quantity of an antimony compound is heated in the upper reduction zone of a Bunsen burner on a thread of asbestos, the flame is given a bluish tinge and when a small porcelain basin filled with cold water is held above it, a brownish-black deposit of metallic antimony is deposited upon the basin, and this is but slightly attacked by cold nitric acid and is insoluble in sodium hypochlorite. Arsenic gives a similar reaction, but arsenic gives a garlic-like odor during the reduction, and the metallic film is readily soluble in the hypochlorite. Antimony compounds may be obtained in solution by treating with HCl or by fusing first with potassium carbonate and potassium nitrate. Hydrogen sulphide produces in acid solution a very characteristic orange-red-colored precipitate of antimony trisulphide. Blowpipe tests—on coal, reducing flame, volatile white coat, bluish in thin layers, continues to form after cessation of blast. With bismuth flux on plaster, orange-red coat, made orange by  $(\text{NH}_4)_2\text{S}$ ; on coal faint yellow or red coat. In open tube, dense, white, non-volatile amorphous sublimate. The sulphide, too rapidly heated, will yield spots of red. In closed tube the oxide will yield a white fusible sublimate of needle crystals; the sulphide, a black sublimate, red when cold.

**Arsenic.**—Mix with sodium carbonate and heat on charcoal with the blowpipe. All arsenic compounds give a garlic odor. Add to concentrated hydrochloric acid a few drops of an arsenite solution and half a cubic centimeter of saturated solution of stannous chloride in hydrochloric acid, warm, and the solution turns brown, then black. Blowpipe—on smoked plaster gives a white coat of octahedral crystals. The action on coal has already been spoken of. With bismuth flux on plaster As gives a reddish-orange coat, made yellow by  $(\text{NH}_4)_2\text{S}$ ; on coal a faint yellow coat. In open tube it gives a white sublimate of octahedral crystals. Too high heat may form brown suboxide or red or yellow sulphide. In closed tube may give white oxide, yellow or red sulphide, or black mirror of metal. Flame—azure blue.

**Barium.**—The Bunsen flame is colored a yellowish-green tint when any volatile barium compound is brought into it. Soluble barium salts are distinguished from those of strontium and calcium inasmuch as they are immediately precipitated by a solution of calcium sulphate. Blowpipe—on coal, with soda, fuses and sinks into the coal. The yellow-green flame can be improved by moistening with HCl.

**Bismuth.**—On charcoal with soda, bismuth gives a very characteristic orange-yellow sublimate. Brittle globules of the metal are also reduced on the charcoal when treated with soda,



**Hydrogen sulphide** precipitates from solutions of bismuth salts a blackish-brown sulphide ( $\text{Bi}_2\text{S}_3$ ) insoluble in ammonium sulphide and easily soluble in nitric acid. Ammonia throws down a white basic salt insoluble in excess. Blowpipe—with bismuth flux (sulphur, 2 parts; potass. iodide, 1 part; potass. bisulphate, 1 part) on plaster, bright scarlet coat surrounded by chocolate brown with sometimes a reddish border. The brown may be made red with ammonia. With bismuth flux, on coal, gives a bright-red coat with sometimes an inner fringe of yellow.

**Cadmium.**—Cadmium is precipitated as a yellow sulphide by hydrogen sulphide. The sulphide is insoluble in ammonium sulphide and in the caustic alkalis. On charcoal with soda, compounds of cadmium give a characteristic sublimate of the reddish-brown oxide.

To test for cadmium in a sulphide, roast it to oxide, and reduce some of the oxide in the upper reducing flame of the Bunsen burner, at the same time holding a glazed porcelain dish which contains water, just above the flame to receive a brown coating. To the brown coating add a drop of  $\text{AgNO}_3$  solution; if Cd is present, black metallic silver will be deposited. Blowpipe—on coal, reducing flame, greenish yellow in thin layers. Beyond the coat, at first part of operation, the coat shows a variegated tarnish. On smoked plaster with bismuth flux Cd gives a white coat made orange by  $(\text{NH}_4)_2\text{S}$ . With borax or sodium phosphate, oxidizing flame, clear yellow hot, colorless cold, can be flamed milk white. The colorless bead touched to  $\text{Na}_2\text{S}_2\text{O}_3$  becomes yellow.

**Cæsium.**— $\text{H}_2\text{PtCl}_6$  produces a bright-yellow crystalline precipitate, a brighter color than the potassium salt thus produced, and is much more soluble than the potassium salt. The flame test is reddish violet, similar to potassium.

**Calcium.**—Calcium compounds moistened with hydrochloric acid and placed on a platinum wire in the hottest part of a Bunsen flame impart a red color to the flame.

Calcium may be precipitated from solution as oxalate by first making the solution ammoniacal and then adding ammonium oxalate or oxalic acid. Blowpipe—on coal with soda, insoluble and not absorbed by the coal. Flame—yellow red, improved by moistening with HCl. With borax or sodium phosphate, clear and colorless; can be flamed opaque.

**Cerium.**—Fuse with sodium carbonate. Treat with dilute hydrochloric acid, evaporate to dryness and bake. Take up with dilute hydrochloric acid, filter. Add ammonia to the filtrate, filter. Dissolve the precipitate in hydrochloric acid, add ammonia and oxalic acid, filter. Dissolve the precipitate in concentrate hydrochloric acid, nearly neutralize with ammonia; add 1 cc. of hydrogen peroxide and then ammonia drop by drop, until just alkaline. When just neutral, white thorium peroxide is precipitated; when ammoniacal, the orange cerium peroxide is precipitated.

**Chromium.**—Chromium oxide is detected in its insoluble compounds by its characteristic green color. It forms an

emerald-green head with borax or microcosmic salt. Caustic potash or soda gives a green precipitate in solution of chromic salts. This dissolves in an excess of alkali in the cold, but is precipitated on boiling the solution. The detection of chromic acid is rendered easy by the bright-yellow color of its salts. The yellow color of the normal chromates becomes red on the addition of an acid, and again yellow when made alkaline. Blowpipe—with borax or sodium phosphate, oxidizing flame, reddish when hot, fine yellow when cold. Reducing flame in borax, green hot and cold. In sodium phosphate, red when hot, green when cold. With soda—oxidizing flame, dark yellow when hot, opaque and light yellow cold. Reducing flame, opaque and yellowish green cold. Manganese interferes, giving a bright yellowish green with soda bead in the oxidizing flame.

**Cobalt.**—Ammonium sulphide produces a black precipitate (CoS) insoluble in acetic acid and in dilute hydrochloric acid. Ammonium sulphocyanate produces a beautiful blue color,  $\text{Co}(\text{CNS})_2$ . With a borax bead cobalt gives the characteristic cobalt-blue color. Blowpipe—on coal, reducing flame, the oxide becomes magnetic metal. The solution in HCl will be rose-red, but on evaporation will be blue. With borax or sodium phosphate, pure blue in either flame.

**Columbium.**—Fuse with potassium bisulphate. Pulverize the fusion and treat it with hot water; then treat it with dilute hydrochloric acid. Digest the residue with ammonium sulphide to remove W, Sn, etc. Wash and treat again with dilute hydrochloric acid. The residue should be colorless and contain only silica and the oxides of columbium and tantalum. This residue in a bead of microcosmic salt is colorless if no columbium is present or if heated in the oxidizing flame; but if heated in the reducing flame, columbium imparts a violet color to the bead, or blue if saturated with oxide. Adding ferrous sulphate turns the bead blood red.

If, when the mixed oxides are boiled in dilute sulphuric acid with metallic zinc, the white precipitate turns intensely blue and remains so on dilution, columbium is present; if it turns bluish gray and colorless on dilution, tantalum is predominant.

**Copper.**—Copper can easily be detected by the reduction to the red metallic bead on charcoal before the blowpipe. Copper compounds moistened with HCl color the non-luminous flame green. An excess of ammonia added to a nitric acid solution of copper produces an azure-blue color. With borax or sodium phosphate, oxidizing flame, green when hot, blue or green blue cold. (By repeated oxidation and reduction, the borax bead becomes ruby red.) Reducing flame, green or colorless hot, opaque and brownish red cold.

**Erbium.**—Erbium oxide heated on a platinum wire colors the flame distinctly green.

**Gallium.**—If a neutral solution of gallium chloride be warmed with zinc, gallium oxide or basic salt separates but not the metal.

**Germanium.**—Fuse with sulphur and sodium carbonate. Treat with hot water, filter, add a few drops of hydrochloric

acid to the filtrate to precipitate white germanium sulphide. Filter and heat the residue in a current of hydrogen to reduce it to gray-black crystalline germanous sulphide. Dissolve the crystals in hydrochloric acid and pass hydrogen sulphide into the solution to precipitate reddish-brown germanous sulphide.

**Glucinum.**—Ammonium carbonate produces a white precipitate,  $\text{GICO}_3$ , soluble in an excess of the reagent; by boiling the solution it is precipitated as a basic carbonate.

**Gold.**—Gold may be reduced from its ores on charcoal to a yellow malleable bead which is soluble in *aqua regia*; if the solution be dropped on filter paper and one drop of stannous chloride added, a purple-red color is produced.

**Indium.**—Heated on charcoal before the blowpipe it colors the flame blue, and gives an incrustation of the oxide. It slowly dissolves in hydrochloric and dilute sulphuric acids, but readily in nitric acid.

**Iridium.**—Ammonium chloride produces in a tolerably concentrated solution of iridium a dark-red crystalline precipitate. Iridium is distinguished from platinum by the formation of a colorless solution of potassium chloriridiate when caustic potash is added to the chloride of the metal, and on exposure to the air this colorless solution first becomes red colored and afterward blue.

Hydrogen sulphide precipitates brown iridium sulphide, which is soluble in ammonium sulphide.

**Iron.**—Ferrous salts with potassium ferricyanide produce a dark-blue precipitate. Ferric salts with ammonia or the fixed alkalis produce a brown precipitate. Ferric salts with potassium or ammonium sulphocyanate produce a blood-red-colored precipitate. Ferrous salts with a bead of microcosmic salt or borax are colored dark green. This color readily changes to yellow or reddish brown by oxidation. Blowpipe—on coal, with reducing flame, many compounds become magnetic. Soda assists this reaction. With borax, oxidizing flame, yellow to red hot, colorless to yellow cold. With reducing flame, bottle green. With tin on coal, violet-green. With sodium phosphate, oxidizing flame, yellow to red hot, greenish when cooling, colorless to yellow cold. Reducing flame, red both hot and cold, greenish when cooling.

**Lead.**—Black precipitate formed with hydrogen sulphide, chrome yellow with chromates. In nitric acid solution dilute sulphuric acid gives a white precipitate of lead sulphate. Blowpipe—on coal, lead is reduced in either flame to malleable metal, and yields near the assay a dark lemon-yellow coat, sulphur yellow cold, and bluish white at border. The phosphate yields no coat without the aid of a flux. With bismuth flux on plaster chrome-yellow coat, blackened by  $(\text{NH}_4)_2\text{S}$ . On coal, volatile yellow coat, darker hot. Flame, azure blue. With borax or sodium phosphate, oxidizing flame, yellow hot, colorless, cold. Flames opaque yellow. In reducing flame, borax bead becomes clear; S. Ph. bead, cloudy.

**Lithium.**—In the Bunsen flame a fine carmine-red color is produced visible if sodium is present by viewing the flame through cobalt glass. If silicon is present, make into a paste with boracic-acid flux and water and fuse in the blue flame. Just after the flux fuses the red flame will appear.

**Magnesium.**—To a solution of magnesium add ammonium chloride, ammonia and sodium phosphate; a white precipitate ( $\text{MgNH}_4\text{PO}_4$ ) forms. The action is hastened by rubbing the sides of the beaker with a glass rod. Blowpipe—on coal, with soda, Mg is insoluble and not absorbed by the coal. With borax or sodium phosphate, clear and colorless; can be flamed opaque white. With cobalt solution, strongly heated, becomes a pale flesh color. (With silicates this action is of use only in absence of coloring oxides. The phosphate, arsenate and borate become violet colored.)

**Manganese.**—Ammonium sulphide produces a flesh-colored precipitate. A solution containing traces of manganese boiled in concentrated nitric acid with lead peroxide or sodium bismuthate and allowed to settle gives a violet-red-colored solution ( $\text{HMnO}_4$ ). The borax bead with manganese in the oxidizing flames gives an amethyst-colored bead (with much, black or opaque) and this in the reducing flame becomes colorless or with black spots. With soda, oxidizing flame, bluish green and opaque when cold. Nitrate assists the reaction. If silicon is present, dissolve in borax, then make soda fusion.

**Mercury.**—Stannous chloride heated with a solution of mercury precipitates gray metallic Hg. Mercury compounds mixed with sodium carbonate and heated in a closed tube produce a gray mirror of metallic Hg. With bismuth flux, on plaster, Hg gives a volatile yellow and scarlet coat. If too strongly heated the coat is black and yellow. On coal Hg gives a coat faint yellow at a distance. In matrass gives mirror-like sublimate, which may be collected in globules. (Gold leaf is whitened by the least trace of mercury vapor.)

**Molybdenum.**—To a strong nitric acid solution of molybdenum add nearly enough ammonia to neutralize the acid and then add a few drops of sodium phosphate solution. A bright-yellow, crystalline precipitate forms when the solution is warmed. A hydrochloric or sulphuric acid solution of molybdenum, to which zinc or stannous chloride is added, turns first blue, then green, and finally brown. On coal, with oxidizing flame Mo gives a coat yellowish when hot, white when cold, crystalline near assay; in reducing flame the coat is turned in part deep blue, in part copper red. Its Bunsen-burner flame is yellowish green. With borax, oxidizing flame, yellow when hot, colorless when cold. Reducing flame, emerald green. The usual chemical test for molybdenum ores is to heat a small piece of the mineral in a porcelain crucible with a drop of sulphuric acid until fumes nearly cease; then cool. A fugitive deep-blue coating appears. The mineral molybdenite, however, must first be oxidized by boiling to dryness with a few

drops of nitric acid, or by roasting in the air. Dr. Moir suggests the following test, which gives a permanent blue. A solution containing a trace of the alkali molybdate is acidified with acetic acid and hydrazine sulphate added. The solution rapidly becomes blue and retains the color even on boiling. The best-known sensitive test for molybdenum is said to be to treat the acid solution with a sulpho-cyanide and then introduce a piece of zinc. A crimson color is produced. If iron is present the blood-red color of the iron compound disappears on the addition of the zinc.

**Neodymium.**—The didymium salts are violet and are identified by a characteristic absorption spectrum.

**Nickel.**—Potassium cyanide produces a bright-green precipitate,  $\text{Ni}(\text{CN})_2$ . When nickel compounds are heated with reducing agents before the blowpipe, an infusible magnetic powder is produced. If this powder is dissolved in a drop or two of dilute nitric acid and evaporated to complete dryness, a characteristic green stain is obtained which becomes yellow on further heating. Nickel compounds color the borax bead brownish yellow in the oxidizing flame, the bead becoming gray and opaque in the reducing flame, owing to the separation of metallic nickel. Nickel is precipitated in alkaline solution by ammonium sulphide, which dissolves in an excess of ammonium sulphide forming a dark-colored solution.

**Osmium.**—It is dissolved in fuming nitric acid, or by fusing with sodium hydroxide and potassium nitrate and then treating with nitric acid and distilling. Osmic oxide ( $\text{OsO}_4$ ), which sublimes at a moderately low temperature, passes over and condenses as a colorless crystalline mass. The osmic oxide has an odor similar to chlorine and is poisonous. A solution containing osmium, either as the tetroxide or any chlorosmiate when heated with thiourea in excess and with a few drops of hydrochloric acid, gives a bright-red or pink color according to the concentration of the osmium present. The reaction is delicate to one part in 100,000. The composition of the red compound is said to be  $\text{Os}(\text{N}_2\text{H}_4\text{CS})_6\text{Cl}_3\cdot\text{H}_2\text{O}$ .

**Palladium.**—Dissolves in nitric acid or *aqua regia*. Potassium iodide added produces a black precipitate, palladous iodide ( $\text{PdI}_2$ ), soluble in an excess of the reagent but not soluble in water, alcohol, or ether. Mercuric cyanide,  $\text{Hg}(\text{CN})_2$ , produces a yellowish-white gelatinous precipitate,  $\text{Pd}(\text{CN})_2$ , which, on ignition, leaves the spongy metal. See also special articles on palladium determination on p. 330.

**Platinum.**—When heated with sodium carbonate on charcoal, gray spongy metal is reduced. This, rubbed on a mortar with a pestle, gives a metallic luster and is insoluble in any single acid. See also special articles on platinum determination on p. 330.

**Potassium.**—A solution of  $\text{H}_2\text{PtCl}_6$  added to concentrated solutions of potassium gives a yellow precipitate  $\text{K}_2\text{PtCl}_6$ . In the Bunsen flame potassium gives a violet color, visible if sodium also is present if viewed through cobalt glass.

**Praseodymium.**—See Neodymium.

**Radium.**—To the Bunsen flame a radium salt imparts an intense carmine-red color. Radium rays discharge a charged electroscope and may be used for making photographs on ordinary X-ray plates.

**Rhodium.**—Before the blowpipe on charcoal with sodium carbonate the salts of rhodium are reduced to the metal, which is insoluble in *aqua regia*, but may be dissolved by fusing it with potassium pyrosulphate and then treating the fusion with water. By adding to this solution potassium hydroxide and a little alcohol the brown rhodium hydroxide is formed.

**Rubidium.**—A solution of  $\text{H}_2\text{PtCl}_6$  produces a white crystalline precipitate,  $\text{Rb}_2\text{PtCl}_6$ , which is less soluble than the corresponding potassium salt and more soluble than the caesium salt. The flame test gives a color similar to the caesium test.

**Ruthenium.**—Ruthenium is practically insoluble in all acids and in *aqua regia*. Fuse it with potassium hydroxide and potassium nitrate. The resulting  $\text{K}_2\text{RuO}_4$ , heated with  $\text{NaCl}$  in a current of chlorine yields soluble  $\text{K}_2\text{RuCl}_6$ . The greenish-black fusion treated with water yields an orange-yellow solution, which stains the skin black.

**Scandium.**—A hydrochloric acid solution of scandium treated with solid sodium silicofluoride and boiled 30 min. gives a precipitate containing scandium free from the rare earth metals.

**Silver.**—When fused with sodium carbonate on charcoal before the blowpipe, a bright metallic silver bead is produced, which may be dissolved in nitric acid and precipitated from the solution by hydrochloric acid as a curdy precipitate of silver chloride, or, if only a trace of silver is present, as a mere opalescence.

**Sodium.**—To a neutral or weakly alkaline solution add potassium pyroantimonate,  $\text{K}_2\text{H}_2\text{Sb}_2\text{O}_7$ , and a heavy white crystalline precipitate,  $\text{Na}_2\text{H}_2\text{Sb}_2\text{O}_7$ , is quickly formed by rubbing the sides of the beaker with a glass rod. Solutions of sodium on a platinum wire in a Bunsen flame give a yellow color.

**Strontium.**—Solutions on a platinum wire color the Bunsen flame carmine red, improved by moistening with  $\text{HCl}$ . Strontium sulphate is less soluble than calcium sulphate, but more soluble than barium sulphate. If barium is present the flame turns brownish yellow. The lithium flame is unaffected by addition of barium chloride.

**Sulphur.**—Fuse on coal with soda and a little borax in the reducing flame and place melt on a bright silver coin. Moisten, crush, and let stand. In presence of sulphur the coin will turn brown or black.

**Thallium.**—Dissolve in dilute acid, add  $\text{H}_2\text{S}$ , filter. Add to the filtrate ammonium sulphide and filter. If thallium is present in the precipitate it will color the Bunsen flame emerald green.

**Thorium.**—Fuse in a platinum crucible with sodium carbonate. Cool, dissolve in water and hydrochloric acid. Evaporate to dryness and bake. Take up with dilute hydrochloric

acid, filter. Add ammonia to the filtrate, filter. Dissolve the precipitate in hydrochloric acid; reprecipitate with oxalic acid, filter, ignite the residue. Dissolve in hydrochloric acid. Evaporate to dryness. Take up with water. Add an excess of sodium thiosulphate and boil to precipitate.

**Tin.**—Mercuric chloride added to a solution of a stannous salt precipitates white mercurous chloride. A trace of stannous chloride in solution added to a solution of gold chloride precipitates finely divided gold, brown by transmitted light and bluish green by reflected light. Metallic zinc precipitates tin from solution as a spongy mass, which adheres to the zinc. Heat the ore on charcoal with sodium carbonate or potassium cyanide; a metallic bead is produced which is coated with white oxide when the flame is removed. Cassiterite in lumps in a test-tube with metallic zinc and dilute sulphuric acid is soon coated with metallic tin.

**Titanium.**—Titanium sulphate with hydrogen peroxide in a slightly acid solution produces an orange-red color, or a clear yellow with small amounts of titanium. Vanadic acid with hydrogen peroxide produces a similar effect. Tin or zinc in hydrochloric acid solutions of titanium produces a violet color due to  $Ti_2Cl_2$ .

**Tungsten.**—Treat with hydrochloric and nitric acids (4:1) and take to dryness, wash by decantation, add dilute hydrochloric acid and metallic zinc, aluminum, or tin and shake; a fine blue coloration or precipitate is produced,  $W_2O_5$ ; the color disappears when diluted with water. Fuse in platinum with potassium bisulphate, digest with a solution of ammonium carbonate, filter, add to the filtrate a few drops of  $SnCl_2$  solution, acidify with hydrochloric acid, warm gently; a fine blue color is produced. The microcosmic salt bead made in the reducing flame is clear blue; if iron is also present, the bead will be red brown. In the oxidizing flame the bead is colorless.

**Uranium.**—Potassium ferrocyanide produces a brown precipitate, in dilute solution a brownish-red coloration. The borax (or microcosmic salt) bead is yellow in the oxidizing flame and green in the reducing flame.

**Vanadium.**—Vanadium compounds can be dissolved by a treatment with acids or alkalis. The hydrochloric acid solution assumes a bright blue color on addition of zinc. A solution of hydrovanadic sulphate cannot be distinguished in color from one of copper sulphate when sufficiently diluted with water, but, of course, does not become colorless in the presence of metallic iron. Solutions of certain vanadates also closely resemble solutions of the chromates. For instance, a solution of the tetravanadate of potassium,  $K_2V_4O_{11}$ , does not differ in appearance from one of potassium dichromate. They may, however, be distinguished from one another, since the vanadate solution becomes blue and the chromate assumes a green color on deoxidation. When a solution of vanadic acid or an acid solution of an alkali vanadate is shaken up with ether containing hydrogen peroxide, the aqueous solution assumes a

red color like that of ferric acetate. This reaction serves to detect one part of vanadic acid in 4000 parts of the liquid. Chromic acid does not interfere with the reaction.

**Yttrium.**—Extract the yttrium in the manner described under Cerium and separate it from the other rare earths in a solution of their sulphates by adding a saturated solution of potassium sulphate. Yttrium sulphate is soluble; the others are not.

**Zinc.**—Ammonium sulphide precipitates ZnS. Potassium ferrocyanide produces a white precipitate,  $\text{Zn}_2\text{Fe}(\text{CN})_6$ . Before the blowpipe on charcoal with sodium carbonate, a coating of oxide is produced which is yellow while hot and white when cold. With cobalt nitrate on charcoal an infusible green mass is produced.

**Zirconium.**—Treat with dilute sulphuric acid (2:1), filter, add ammonia to the cold filtrate, filter; wash, dissolve the precipitate in hydrochloric acid, evaporate to dryness. Take up with a little water and add to the cold saturated solution hydrochloric acid, drop by drop; if zirconium is present, the oxychloride will be precipitated. Heat to dissolve the precipitate. Cool and after some time fine silky needles of  $\text{ZrOCl}_2 + 8\text{H}_2\text{O}$  will precipitate.

## DETERMINATION OF PLATINUM, PALLADIUM AND GOLD<sup>1</sup>

Scorify the lead buttons from two or more  $\frac{1}{2}$ -a.t. crucible fusions together, adding at least six times as much silver as the combined weight of the Pt, Pd and Au present, and cupel *hot*. In rich materials such as slimes or concentrates, two  $\frac{1}{2}$ -a.t. fusions suffice, but low-grade ores may require 10 or more  $\frac{1}{2}$ -a.t. fusions combined for each determination.

Part the silver beads with  $\text{HNO}_3$  (1:6), followed by stronger parting acid (1:1) and wash with water as usual. All Pd goes into solution, together with considerable Pt. The residue consists of Au plus some Pt. Dissolve residue in strong *aqua regia* and reserve the solution (solution A). Precipitate the silver in the nitric-acid solution—containing Ag, Pd and some Pt—with HCl. Practically all the Pt will remain in solution; but the precipitated  $\text{AgCl}$  is pink in color and contains considerable Pd. Filter off the  $\text{AgCl}$ , scorify and cupel it and part again with  $\text{HNO}_3$  (1:6); all should dissolve. Reprecipitate the Ag with HCl. The liquid now contains most of the remaining Pd, but some is co-precipitated with  $\text{AgCl}$ . Filter off the  $\text{AgCl}$  and add the filtrate to the first filtrate from  $\text{AgCl}$ . Again scorify and cupel the silver chloride, dissolving the silver in nitric acid as before and reprecipitating the silver as chloride. In most cases the filtrate from this silver chloride contains all the remaining Pd. \* If, however, the  $\text{AgCl}$  is distinctly pink, another separation must be made.

<sup>1</sup> From an article by A. M. SMOOT, *Eng. and Min. Journ.*, Apr. 17, 1915.



Unite all filtrates from AgCl precipitations and evaporate to small bulk, adding the *aqua-regia* solution of the Au and Pt (solution A). The liquid now contains all the Au, Pt and Pd present in the original ore, together with traces of Ag due to solubility in AgCl in excess of HCl, and also traces of Pb gathered from the lead retained in the silver buttons from the several recupellations.

Evaporate the liquid to dryness on the steam bath; take up with dilute HCl (1:3) and evaporate again to dryness; take up with five drops of HCl and 40 cc.  $H_2O$ .<sup>1</sup> Pay no attention to any insoluble residuc of AgCl or  $PbCl_2$ .<sup>1</sup> Precipitate gold by adding, say, 3 grams of oxalic acid to the solution and boiling it. Let stand over night and filter off the Au. If Pt and Pd are high, it is necessary to redissolve the Au in *aqua regia*, evaporating with HCl to dryness and repeating the oxalic-acid precipitation, uniting the filtrate with that from the first gold precipitation. Burn the filter containing the gold and scorify it with six times its weight of silver and a little test lead; cupel, part and weigh the gold as usual.

To the oxalic-acid filtrates from Au add 5 cc. of HCl and make volume up to 150 cc.; heat to boiling and precipitate Pt and Pd with a rapid current of  $H_2S$  in *hot* solution, passing the current of gas for some time and keeping the solution hot during precipitation. Filter and wash the Pt and Pd sulphides with  $H_2S$  water containing a little HCl. Wash the precipitate from the filter with a fine water jet into an original beaker; spread the filter paper (which will contain a small amount of precipitate impossible to wash off) with the precipitate side down over the lower side of a watch-glass cover. Add *aqua regia* to the precipitate in the beaker and place the cover on the beaker; warm gently to dissolve the Pt and Pd sulphides. The fumes arising from the acid dissolve the traces of Pt and Pd adhering to the filter paper. When solution is complete and the filter paper is white, remove the watch-glass cover and wash the paper with hot dilute HCl thrown against it in a fine stream.

Evaporate the *aqua-regia* solution to dryness, take up the residue with HCl and evaporate again to dryness to remove all  $HNO_3$ . Take up the residue with two or three drops of HCl and about 2 cc. of  $H_2O$ . The solution is usually perfectly clear, but it may be slightly cloudy owing to the presence of a little AgCl in it. No attention need be paid to this, however. Add 5 to 10 cc. of a saturated solution of  $NH_4Cl$ , stir well and allow to stand over night. Platinum is precipitated as ammonium-platinum chloride— $(NH_4)_2PtCl_6$ . Filter and wash the precipitate with 20 per cent.  $NH_4Cl$  solution. All Pd passes into

<sup>1</sup> In materials rich in palladium the small amount of  $AgCl + PbCl_2$  may be distinctly pink in color and retain weighable quantities of Pd. If this is the case, the Pd may be recovered in the solution from the nitric acid parting of the gold. To do this, precipitate the silver in this liquid by adding HCl, filter off the silver chloride and evaporate the filtrate to dryness. Take up with a drop of HCl and a little water, let stand over night and filter through a very small filter. This liquid may be added to solution B before precipitating palladium with glyoxime.

the filtrate which is reserved (solution *B*). Dissolve the Pt precipitate in boiling hot 5 per cent.  $\text{H}_2\text{SO}_4$ ; heat the liquid to actual boiling and precipitate with  $\text{H}_2\text{S}$  as before, filtering and washing with  $\text{H}_2\text{S}$  water. Burn the filter and precipitate at a low temperature in a scorifier; add six times as much Ag as Pt, scorifying with lead, cupel and part the silver bead containing the platinum with  $\text{H}_2\text{SO}_4$ ; decant off the silver solution and wash once with strong  $\text{H}_2\text{SO}_4$ , followed by 50 per cent.  $\text{H}_2\text{SO}_4$  until practically all silver is washed away; finally wash with water, anneal and weigh. A minute quantity of Ag is retained with the platinum, but it can usually be neglected. In very important work where the amount of platinum is large dissolve in *aqua regia*, evaporate the solution to dryness, take up with a drop of  $\text{HCl}$ , dilute largely with water and let the  $\text{AgCl}$  settle over night; filter on a small paper, cupel it with a little sheet lead and deduct the weight from the weight of platinum. This refinement need not be considered in materials running less than 15 or 20 oz. to the ton.

It may seem an unnecessary step to precipitate the platinum as sulphide, scorify it with silver and part it as described in the foregoing. General practice has been to ignite the ammonium-platinum-chloride precipitate and weigh the metallic residue. When this is done, however, there is danger of losing considerable platinum, which is carried away mechanically during the decomposition of the compound; furthermore, it is extremely difficult (if not impossible) to collect the finely divided residue for weighing, and the precipitate invariably contains lead and silver. Precipitation as sulphide, scorification and cupellation with excess silver and parting with sulphuric acid overcome the difficulties inherent in handling the ammonium precipitate.

The palladium is all contained in the filtrate and washings from the platinum-ammonium-chloride precipitates (solution *B*). Add to this solution at least seven times as much dimethylglyoxime as there is Pd present (in any case, at least 0.1 gram glyoxime). The precipitant should be dissolved in a mixture of two-thirds strong  $\text{HCl}$  and one-third water. Dilute the liquid to 250–300 cc., heat on a steam bath for half an hour and let stand over night. Pd is precipitated as a voluminous, yellow, easily filtered glyoxime compound  $(\text{C}_5\text{H}_{14}\text{N}_4\text{O}_4)_2\text{Pd}$ , containing, when dried at  $110^\circ\text{C}$ ., 31.686 per cent. of Pd. Filter the Pd precipitate on a weighed Gooch crucible and wash it first with dilute  $\text{HCl}$ , half and half, then with warm water and finally with alcohol; dry it at  $110^\circ$  to  $115^\circ\text{C}$ . and weigh. The disadvantage of weighing palladium on a Gooch crucible is overcome—at least to some extent—by the fact that the Pd compound contains a relatively small amount of Pd—less than one-third of its weight. This compound may also be weighed on carefully counterpoised papers; but it is better to use Gooch crucibles, if they are available, because of the relatively strong acid which is required for washing. The object in using half-and-half hydrochloric acid as a wash liquid is to dissolve out any excess of the glyoxime

precipitant. This is easily soluble in moderately strong HCl, but is substantially insoluble in water.

### DETERMINATION OF SILVER IN ORES AND CONCENTRATES CONTAINING PLATINUM AND PALLADIUM

Make the usual crucible fusion on one-quarter, one-half or full assay ton, according to the amount of silver present. Instead of cupeling the lead button, hammer it free from slag and dissolve it in dilute nitric acid. Most of the silver passes into solution together with palladium, and perhaps a trace of platinum; but gold and most of the platinum remain insoluble. The gold and platinum retain an appreciable proportion of silver which cannot be washed out. Filter out the insoluble residue and wash it thoroughly with hot dilute nitric acid, followed by hot water. Scorify the residue once more with a little lead and dissolve the lead button as before, filtering into the beaker containing the first filtrate. In this liquid precipitate the silver as AgCl by adding standing NaCl in sufficient quantity; stir well, and if the amount of silver is small, add about  $\frac{1}{2}$  cc. of strong  $H_2SO_4$  to form a precipitate of lead sulphate. Let the silver chloride, or the silver chloride plus lead sulphate, settle over night or until the supernatant liquid is clear; filter through double filter papers; ignite and scorify the residue of silver chloride with test lead.

If the amount of palladium contained in the sample is small, the silver bead obtained by cupeling the lead button obtained by scorifying the silver chloride may be considered as sufficiently pure for ordinary purposes. It contains, of course, some palladium, and in accurate silver determinations the lead button from the first silver-chloride precipitation should be redissolved and the silver reprecipitated, filtered and scorified as before. The amount of palladium retained after the second precipitation and scorification is so small as to be negligible.

### SCHEME FOR QUALITATIVE ANALYSIS OF HEAVY METALS AND ALKALINE EARTHS

(The material is either in solution or is capable of being readily dissolved.)

(A) Slightly acidulate solution with HCl. It is best to take only a small portion of the solution, and if a precipitate forms, see whether it redissolves in more acid. If it does, it indicates Sb or Bi. Permanent precipitate shows Ag, Pb, or Hg (ous). Filter precipitate (B) and reserve solution (C).

(B) Wash with hot water, and add  $K_2Cr_2O_7$  solution to filtrate. Heavy yellow precipitate shows lead. Wash residue (B) with  $NH_4OH$ , and acidulate filtrate with  $HNO_3$ . Precipitate shows Ag. Blackening of filter paper shows Hg (ous). (C) Pass in  $H_2S$  until precipitate coagulates. Precipitate may be As (yellow), Sb (orange),  $Sn''$  (brown),  $Sn'''$  (yellow),

Hg' or Hg'' (black), Bi (brown), Cd (yellow), Pb (black), Cu (black). Filter, giving precipitate (*D*) and solution (*E*).

(*D*) Warm with ammonium polysulphide and filter. Filtrate (*G*) may contain As, Sb, Sn, and traces of Cu. (Also Au, Ir, Se, W, Pt, Te, V, of the rare elements.) Precipitate (*E*) contains Hg, Bi, Cd, Pb, Cu.

(*E*) Boil off all  $H_2S$  from the filtrate from the  $H_2S$  precipitation, making sure finally that it is all gone by adding a few drops of  $HNO_3$  and boiling. If organic acids, tartaric, citric, or the like are present, it is best to destroy them by evaporating almost to dryness and adding some concentrated  $H_2SO_4$  and fuming  $HNO_3$ . Test a little of the solution for phosphoric acid by means of ammonium-molybdate solution in nitric acid. If a yellow precipitate shows phosphates, evaporate to a thick soup, and add a little tin and nitric acid and boil until action ceases. Dilute, filter and repeat. The phosphorus is removed as stannous phosphate, all but traces of the tin remain undissolved as metastannic acid. If only traces of the further groups of metals are being looked for, boil off all the nitric acid with repeated additions of  $HCl$ , throw out the last of the tin with  $H_2S$ , filter, then boil off the  $H_2S$  and remove the last traces of it with  $HNO_3$ , as above specified. If phosphorus is not present, all of this is unnecessary. Add a little  $NH_4Cl$  and make the solution ammoniacal. Fe, Al and Cr are precipitated<sup>1</sup> (*L*). Boil off excess of ammonia, filter; solution (*M*) contains Co, Mn, Ni, and Zn and the alkaline earths and alkalis.

(*F*) Heat residue from ammonium polysulphide leaching with dilute (10 per cent.)  $HNO_3$  and filter. Heat residue with concentrated  $HNO_3$ , dilute and filter, combining the two filtrates. The precipitate (*H*) remaining consists of  $HgS$  and S. The filtrate (*I*) contains Cd, Bi, Cu, Pb.<sup>2</sup> (If the original treatment is made with concentrated  $HNO_3$  all of the  $PbS$  may be oxidized to  $PbSO_4$  and remain with the mercury.  $PbS$  is soluble in 10 per cent.  $HNO_3$  according to the equation  $PbS + 2HNO_3 = Pb(NO_3)_2 + H_2S$ ).

(*G*) Throw down precipitate from  $(NH_4)_2S_2$  solution with  $HCl$ . Leach precipitate with ammonium carbonate. Arsenic dissolves. Filter. Add  $HCl$  to filtrate to faint acidity. Pass in  $H_2S$ . Yellow precipitate shows arsenic. (May be confirmed by MARSH test.) Dissolve remainder of precipitate *E* in strong  $HCl$ . Dilute and add metallic zinc in contact with a small piece of platinum. Precipitate of metallic tin and antimony forms. Treat with  $HCl$  and filter. To filtrate add  $HgCl_2$  solution. White to gray precipitate of  $Hg_2Cl_2$  shows tin. Treat residue from extraction with *aqua regia*, boil off excess  $Cl$  and  $HNO_3$ , and pass in  $H_2S$ . An orange precipitate of

<sup>1</sup> The hydroxide precipitate will carry down As, Sb, Se, Te, Sn, P and Ti if they are present, which reaction affords an easy way to concentrate these elements from a large bulk of copper in exact copper analysis.

<sup>2</sup> Pd and Os belong in the  $H_2S$  group of metals whose sulphides are insoluble in  $(NH_4)_2S_2$ .

$\text{Sb}_2\text{S}_3$  confirms the presence of antimony, already indicated by a blackening of the platinum.

(H) Dissolve precipitate in *aqua regia*. Boil off excess of  $\text{Cl}$  and  $\text{HNO}_3$  and add  $\text{SnCl}_2$ . A white to gray precipitate confirms presence of mercury, probably already indicated by the black residue from the  $\text{HNO}_3$  leaching.

(I) Add a few drops of  $\text{H}_2\text{SO}_4$  to solution. White precipitate indicates lead. Filter, getting precipitate (J) and solution (K).

(J) Treat precipitate on filter with hot ammonium acetate and filter, adding  $\text{K}_2\text{Cr}_2\text{O}_7$  to filtrate. Chrome-yellow precipitate confirms presence of lead.

(K) Evaporate to small bulk, add about eight times bulk of alcohol, warm and filter (to ensure removal of all lead). Evaporate off alcohol on sand bath and make strongly ammoniacal. White precipitate indicates Bi. Blue solution indicates Cu. The blue may be so intense as to mask the  $\text{Bi}(\text{OH})_3$  precipitate. Filter and wash, and treat filter paper with strong  $\text{HCl}$ , catching strong  $\text{HCl}$  solution in a beaker. Dilute largely. White precipitate shows Bi. Take blue copper solution and add  $\text{KCN}$  solution until blue color just disappears and pass in  $\text{H}_2\text{S}$ . Bright-yellow precipitate indicates Cd.

(L) Leach precipitate with hot  $\text{KOH}$  solution. Make leachings acid with  $\text{HCl}$  and add ammonia. White flocculent precipitate indicates alumina. Dissolve half of original precipitate with  $\text{HCl}$  and add  $\text{K}_4\text{Fe}(\text{C}_2\text{O}_4)_3$ . Precipitate of Prussian blue confirms presence of iron, probably already indicated by red color of precipitate. Take the other half of the precipitate and fuse with sodium carbonate and sodium nitrate. A yellow melt indicates sodium chromate. Dissolve melt in water, acidify with acetic acid and add a drop of lead-acetate solution. Precipitate of lead chromate confirms presence of chromium, probably already indicated by a greenish hydroxide precipitate or the yellow melt.

(M) Pass in  $\text{H}_2\text{S}$  into solution.  $\text{Mn}$ ,  $\text{Zn}$ ,  $\text{Co}$ ,  $\text{Ni}$  precipitate. Filter. Filtrate (N) contains alkalis and alkaline earths. Treat precipitate with cold dilute  $\text{HCl}$ .  $\text{Mn}$  and  $\text{Zn}$  dissolve. Add  $\text{KOH}$  in excess. Filter, acidify filtrate with acetic acid and pass in  $\text{H}_2\text{S}$ . A white or nearly white flocculent precipitate confirms the presence of  $\text{Zn}$ . Take the precipitate from the  $\text{KOH}$  precipitation and fuse with  $\text{Na}_2\text{CO}_3$  and  $\text{NaNO}_3$ . A green melt shows manganese. Take the residue insoluble in  $\text{HCl}$  and touch a borax bead to it and heat. A bead, violet when hot, blue when cold, shows cobalt. A gray bead (cold) shows  $\text{Ni}$  only, but this is easily masked by cobalt blue. So if the bead is blue, dissolve the residue in *aqua regia*, evaporate to soup, dilute, and add  $\text{HCN}$  until the precipitate first formed redissolves. Heat solution gently, add a little  $\text{NaOH}$ , then  $\text{Br}$  (under a hood). A black precipitate shows nickel.

(N) Boil until  $\text{H}_2\text{S}$  odor becomes faint, add  $\text{NH}_4\text{OH}$  and  $(\text{NH}_4)_2\text{CO}_3$  and warm slightly.  $\text{Ba}$ ,  $\text{Sr}$ , and  $\text{Ca}$  precipitate. Filter and dissolve precipitates in  $\text{HCl}$ . Add  $\text{H}_2\text{SO}_4$  to part of

the solution. Precipitate indicates Ba or Sr or both. To another part of the solution add  $K_2CrO_4$ . An immediate precipitate of a pale yellow color shows Ba. In the filtrate Sr can be determined by the reddish color given a Bunsen burner flame, while Ca can be precipitated as calcium oxalate (white) in ammoniacal solution. Calcium colors a Bunsen flame reddish yellow, and Ba a vivid green.

(O) Add ammonium- or sodium-phosphate solution to the filtrate from the Ba, Ca, Sr precipitation. Stir, cool, and allow to settle over night. Granular white precipitate shows Mg.

### Qualitative Tests for Acids<sup>1</sup>

The acid-radicals cannot be advantageously precipitated in groups, and the members separated and identified as with the metals. They are usually detected in the course of analysis by special tests. They may, however, be arranged in groups of such acid-radicals as resemble one another. A consideration of the metals present, in case the material is in solution, will often rule out many acids as possibilities at once.

The acids may be arranged as follows:

**Group I.**—Acids which are precipitated by  $AgNO_3$  in presence of nitric acid.

Hydrosulphuric acid	$H_2S$
Hydrochloric acid	$HCl$
Hydrobromic acid	$HBr$
Hydriodic acid	$HI$

**Group II.**—Acids whose salts deflagrate on charcoal.

Nitric acid	$HNO_3$
Chloric acid	$HClO_3$

**Group III.**—Acids which cannot be classified.

Boric acid	$H_3BO_3$
Carbonic acid	$H_2CO_3$
Chromic acid	$H_2CrO_4$
Hydrofluoric acid	$HF$
Phosphoric acid	$H_3PO_4$
Silicic acid	$H_4SiO_4$
Sulphuric acid	$H_2SO_4$
Arsenic acid	$H_3AsO_4$
Hydrocyanic acid, acetates	$HCN$

### GROUP I

$H_2S$ .— $AgNO_3$  gives a black pp. of  $Ag_2S$  insoluble in dilute acids.

Lead acetate—a black pp. of  $PbS$  insoluble in dilute acids.

Dilute  $HCl$ —many sulphides when heated with dilute  $HCl$  evolves  $H_2S$ , which blackens paper moistened with lead acetate.

<sup>1</sup> JAMES PARK, "A Text-Book of Practical Assaying," with some original additions.

If much  $\text{H}_2\text{S}$  is present, there will be the characteristic odor present, but do not smell the gas coming off unless you are sure no cyanides are present. It is safer to have some one else smell it, anyway.

**HCl.**— $\text{AgNO}_3$ —a white pp. of  $\text{AgCl}$  at first white, turns violet on exposure to light. Readily soluble in ammonia and  $\text{KCN}$ . Insoluble in dilute nitric acid.

Lead acetate—a white pp. of  $\text{PbCl}_2$  soluble in hot water.

Strong  $\text{H}_2\text{SO}_4$ —when heated with dry chlorides causes evolution of  $\text{HCl}$  gas, chlorides of  $\text{Hg}$  and  $\text{Sn}$  excepted. Bromides, iodides, fluorides, cyanides, carbonates, sulphides, sulphites, thiosulphates and acetates also give off characteristic gases during this test.

$\text{MnO}_2 + \text{H}_2\text{SO}_4$ —when mixed with a chloride causes evolution of chlorine, which bleaches wet litmus paper or a green leaf. Iodine and bromine are also evolved by this means. The colors are characteristic.

**HBr.**— $\text{AgNO}_3$ —a yellowish-white pp. of  $\text{AgBr}$ ; sparingly soluble in ammonia but readily in  $\text{KCN}$ . Insoluble in dilute nitric acid. Phosphates also give a yellow precipitate. Test for phosphoric acid in ammonium molybdate in  $\text{HNO}_3$  solution.

Lead acetate—a white pp. of  $\text{PbBr}_2$ .

Strong  $\text{H}_2\text{SO}_4$ —with a dry bromide causes evolution of  $\text{HBr}$  vapors.

$\text{MnO}_2 + \text{H}_2\text{SO}_4$ —causes evolution of  $\text{Br}$ , which turns starch paper yellow.

Chlorine water or  $\text{HCl} +$  two drops of  $\text{NaClO}$ , when added, drop by drop, to a solution of a bromide liberates  $\text{Br}$ , which colors solution orange red. Avoid excess of  $\text{Cl}$ , as it destroys color. When a portion is warmed, reddish-brown vapors are given off. If three drops of  $\text{CS}_2$  are added, the  $\text{Br}$  will sink to the bottom.

**HI.**— $\text{AgNO}_3$ —a yellowish-white pp. of  $\text{AgI}$ . Sparingly soluble in ammonia; readily in  $\text{KCN}$ . Insoluble in dilute nitric acid.

Lead acetate—bright yellow pp. of  $\text{PbI}_2$ .

Chlorine water—reacts for iodine, giving a brown solution and violet vapors. To a portion add starch solution, an intense blue is produced.

## GROUP II

### Nitric Acid (Nitrates)<sup>1</sup>

**Dry Reactions.**—1. If a nitrate is heated on charcoal it deflagrates, the charcoal burning at the expense of the  $\text{O}$  of the nitrate. Nitrites, chlorates, chromates, manganates and permanganates also give this reaction.

2. If a mixture of a nitrate and  $\text{KCN}$  powder be heated on platinum foil, deflagration takes place. This is a delicate test.

**Wet Reactions.**—1. Strong  $\text{H}_2\text{SO}_4$  heated with nitrate causes evolution of fumes of nitric acid. Nitrites give this reaction.

<sup>1</sup> Nitrites also give most of these reactions.

2. Mix sol. of a nitrate with strong sol. of  $\text{FeSO}_4$ . Hpld test-tube in a slanting position and pour strong  $\text{H}_2\text{SO}_4$  down to bottom. A purple or brown color will mark the plane of contact of the fluids. Nitrites also give this and the following reaction.

3. Copper filings and  $\text{H}_2\text{SO}_4$  heated with a nitrate liberate  $\text{NO}$ , which becomes peroxidized to  $\text{NO}_2$  on contact with the air.

4. A sol. of indigo boiled with  $\text{HCl}$  and a sol. of a nitrate is decolorized. Not characteristic, as chlorine reacts the same.

5. A little brucine dissolved in  $\text{H}_2\text{SO}_4$  when added to a sol. of a nitrate gives a fine red color. This is a very delicate test.

6. Free nitric acid may be detected by evaporating to dryness with quill-cuttings. These will be colored yellow.

It gives with  $\text{FeSO}_4$  a brown ring; and with copper filings or foil a reddish-brown gas,  $\text{NO}_2$ , and a blue color.

The most delicate test for nitrates is to take 2 or 3 cc. of the solution in  $\text{HCl}$ , add 12 drops of a solution of diphenylamine in sulphuric acid, then run in  $\text{H}_2\text{SO}_4$  below the mixture. A faint blue will be given by 1 part in 1,000,000 of  $\text{HNO}_3$ .

### Chloric Acid (Chlorates)

*Dry Reactions.*—1. Chlorates when heated on charcoal deflagrate far more violently than nitrates. So do perchlorates.

2. Heated on charcoal with  $\text{KCN}$ , chlorates detonate violently. Use only small quantities in this experiment.

*Wet Reactions.*—1. A few drops of  $\text{H}_2\text{SO}_4$  added to a small quantity of a chlorate liberate chlorine peroxide ( $\text{ClO}_2$ ) which colors the  $\text{H}_2\text{SO}_4$  intensely yellow, and has a strong odor of  $\text{Cl}$  and a greenish color. This experiment should be tried in a watch-glass *without heat*, as an explosion might take place.

2. If a cold sol. of indigo is added to a cold sol. of a chlorate till distinctly blue, and some  $\text{H}_2\text{SO}_4$  then poured in and shaken, the blue color of the indigo is at once destroyed. Chlorites, perchlorates, and hypochlorites also give this reaction.

3. If a chlorate is mixed with  $\text{Na}_2\text{CO}_3$  and ignited,  $\text{O}_2$  is given off and a chloride remains. On dissolving the residue, acidifying with nitric acid, and adding silver nitrate, a white pp. of  $\text{AgCl}$  is formed.

## GROUP III

### Boracic Acid

*Dry Reactions.*—1. Boric acid tinges the Bunsen flame green.

2. Pour some methylated spirits on finely powdered borax in a porcelain dish; add a little  $\text{H}_2\text{SO}_4$ ; mix and ignite; the flame will show a green edge.

*Wet Reactions.*—1. If a sol. of an alkaline borate is mixed with  $\text{HCl}$  to slight but distinct acid reaction, and a strip of turmeric paper is *half dipped* into it and then dried at  $212^\circ\text{F}$ . ( $100^\circ\text{C}$ .), the dipped half will show a peculiar red color—very delicate. Sodium carbonate turns this to a dark blackish-green, and  $\text{HCl}$  will restore the color.



### Carbonic Acid

*Wet Reactions.*—1. Almost any acid when poured on a carbonate in a test-tube causes effervescence due to rapid evolution of  $\text{CO}_2$ . When conducted into lime-water this gas causes a pp. of  $\text{CaCO}_3$ , which is sol. in large excess of the gas. Cyanides, sulphites, tellurides, selenides, sulphides, and thiosulphates also effervesce. Be careful not to inhale the gases from these compounds.

### Chromic Acid

*Dry Reactions.*—1. Compounds of chromic acid give an emerald-colored bead with borax on platinum loop in both outer and inner blowpipe flames.

*Wet Reactions.*—1.  $\text{H}_2\text{S}$  added to an acidified sol. of a chromate produces a green coloration due to reduction of the chromic acid  $[\text{CrO}_3]$ . A white precipitate of sulphur is formed at the same time.

(Readily oxidizable substances deoxidize  $\text{K}_2\text{Cr}_2\text{O}_7$  with production of a chromic salt; the color of the solution at the same time changes from orange red to bright green.)

2.  $\text{H}_2\text{O}_2$  or  $\text{BaO}_2$  if added to a cold acidified sol. of a chromate produces an intense blue coloration, which becomes fixed if ether is first added and the liquid well shaken after adding the peroxide. The ether assumes and retains the blue color. A few drops of  $\text{HNO}_3$  are useful. This is an extremely delicate and characteristic test.

3.  $\text{BaCl}_2$  gives a light yellow pp. of  $\text{BaCrO}_4$ , sol. in  $\text{HCl}$  and  $\text{HNO}_3$ .

4.  $\text{AgNO}_3$  gives a dark purple-red pp. of  $\text{Ag}_2\text{CrO}_4$ , sol. in  $\text{KNO}_3$  and  $\text{NH}_4\text{OH}$ .

5.  $\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$  gives a yellow pp. of  $\text{PbCrO}_4$ , sol. in  $\text{KOH}$ , but insol. in  $\text{C}_2\text{H}_3\text{O}_2$ . This precipitate, "chrome yellow," is very characteristic.

6. If insoluble chromates are fused with  $\text{Na}_2\text{CO}_3$  and  $\text{KNO}_3$ , alkaline chromates will be formed, which are soluble in water.

### Hydrofluoric Acid

The ordinary tests for a fluoride depend on the liberation of  $\text{HF}$ , which is allowed to etch glass.

1. If strong  $\text{H}_2\text{SO}_4$  is warmed with a little finely powdered  $\text{CaF}_2$  in a test-tube,  $\text{HF}$  is liberated.

2. Cover the convex side of a watch-glass with melted paraffin or wax. Trace lines near the middle of the glass with the point of a penknife so as to remove the wax from these parts, but not to scratch the glass. Place the prepared glass on the top of a platinum crucible containing the material to be tested and some strong  $\text{H}_2\text{SO}_4$ . Pour a few drops of water into the watch-glass to keep it cool, and gently heat the bottom of the crucible. Allow to stand for 20 minutes. Melt off wax, and on the clean surface the etched lines will be visible. If small

traces of a fluoride were present, the tracing will become visible by breathing on the cold surface of the glass.

This reaction fails when there is too much  $\text{SiO}_2$  present, as the  $\text{H}_2\text{SO}_4$  then liberates  $\text{SiF}_4$  instead of  $\text{HF}$ .

$\text{SiF}_4$  does not etch glass, but produces white fumes in moist air; when these fumes are conducted into water a colorless flocculent pp. of gelatinous silica is separated.



3.  $\text{CaCl}_2$  when added to the solution of a fluoride gives an almost transparent gelatinous pp. of  $\text{CaF}_2$ , which becomes more visible when the liquid is heated or when ammonia is added.

### Phosphoric Acid

*Wet Reactions.*—1.  $\text{MgSO}_4$  solution (to which ammonium chloride has been added and then a little ammonia) gives with the solution of a phosphate a white crystalline pp. of magnesium ammonium phosphate ( $\text{MgNH}_4\text{PO}_4 + 6\text{H}_2\text{O}$ ) which rapidly settles. This pp. is insol. in  $\text{NH}_4\text{OH}$ , but is readily sol. in acids, even  $\text{C}_2\text{H}_4\text{O}_2$ . If very little phosphate is present, the pp. often appears only after the solution has been warmed and allowed to stand.

2. Silver nitrate throws down from neutral solutions a light yellow pp. of  $\text{Ag}_3\text{PO}_4$ , readily soluble in nitric acid and ammonia.

3. The solution of ammonium molybdate in nitric acid gives in the cold a finely divided yellow pp. which settles rapidly. With small quantities of phosphate, a few hours must be allowed for the reaction, and the liquid may be warmed gently, but not above  $40^\circ\text{C}$ . ( $104^\circ\text{F}$ .). Not more than an equal volume of the fluid to be tested should be added to the molybdate. Large quantities of  $\text{HCl}$  interfere with the precipitation.

The pp. after subsiding may be separated by filtering, washed with ammonium molybdate solution, then dissolved in ammonia, and, by adding  $\text{NH}_4\text{Cl}$  and  $\text{MgSO}_4$  as in (1), the pp. of  $\text{MgNH}_4\text{PO}_4 + 6\text{H}_2\text{O}$  may be obtained.

The solution to be tested must not be alkaline to test paper, but should be made distinctly acid with  $\text{HNO}_3$ . It should then be added in *small quantities* only to some  $\text{NH}_4\text{HMoO}_4$  sol. in a test-tube, more being added if no yellow pp. forms after a few minutes, when the liquid may be gently warmed.

### Arsenates

The pps. found in (1) and (3) with a phosphate are precisely the same as those formed when an arsenate is present.  $\text{AgNO}_3$  gives with an arsenate a brown pp.; with a phosphate a yellow pp.; and ammonium molybdate solution gives a pp. with an arsenate only after boiling instead of gently heating as with a phosphate. It is also possible to remove the arsenic with  $\text{H}_2\text{S}$  in  $\text{HCl}$  solution before making confirmatory tests for phosphates.

### Silicic Acid

**Dry Reaction.**—1. If a fragment of silica or a silicate is heated in a bead of microcosmic salt, it remains undissolved and floats about in the bead as a more or less transparent mass, which retains its original shape. In the case of a silicate the bases dissolve out.

**Wet Reactions.**—2.  $\text{NH}_4\text{Cl}$  produces in not too dilute solutions of alkaline silicates a pp. of hydrated  $\text{SiO}_2$ .

3. The solutions of alkaline silicates are decomposed by all acids, the  $\text{SiO}_2$  separating as the gelatinous hydrate. The acid should be added drop by drop and the solution stirred.

### Sulphate Group

**REMARKS.**—Sulphates are the only commonly occurring salts which give with  $\text{BaCl}_2$  a pp. insoluble in boiling  $\text{HCl}$ . (Selenates also give a pp. of  $\text{BaSeO}_4$  with  $\text{BaCl}_2$ , but it dissolves on boiling with strong  $\text{HCl}$  for some time.)

### Tests for Sulphates ( $\text{SO}_3$ , and a Base)

**Wet Reactions.**—1. All solutions of the sulphates give with  $\text{BaCl}_2$  a white pp. of  $\text{BaSO}_4$  which is insoluble in all acids.

2. If a sulphate or any solid substance containing sulphur is mixed with pure solid  $\text{Na}_2\text{CO}_3$  and fused on charcoal in the inner reducing blowpipe flame, it will yield  $\text{Na}_2\text{S}$ .

Detach the cold fused mass with the point of a knife, place a portion on a bright silver coin, and moisten with  $\text{H}_2\text{O}$ . Allow to remain a short time, and then rinse off; a black stain of  $\text{Ag}_2\text{S}$  will be seen upon the coin, if sulphur is present.

3. Lead acetate produces a heavy white pp. of  $\text{PbSO}_4$ , which dissolves readily in hot strong  $\text{HCl}$ , or alkaline acetates.

4. Sulphuric acid gives, with sugar, a black mass.

5. To detect free sulphuric acid, mix the fluid with a very little cane-sugar and evaporate to dryness at  $212^\circ\text{F}$ . ( $100^\circ\text{C}$ .). If any is present, a black residue will remain; or with small traces a blackish-green residue. No other free acid decomposes cane-sugar in this way.

### Cyanides and Acetates

**Cyanides.**—These give a blue color with a mixture of ferrous and ferric salts.

Acetates evolve a characteristic odor when present in large quantity in strong sulphuric-acid solution. They give a blood-red solution with ferric salts. If the solution be neutral the iron is precipitated on boiling.

Some additional tests for other acids are:

A concentrated solution in hydrochloric acid will, when  $\text{H}_2\text{S}$  is passed in, give a precipitate of sulphur if it contains nitrates, nitrites, chlorates, sulphites, thiosulphates, arsenates, chromates, manganates or permanganates.

## SOME PROPERTIES OF RADIOACTIVE SUBSTANCES

The table below is based on tables in *Le Radium*, Jan., 1909, Jan., 1910 and Jan., 1911, and in *Zeit. für Angew. Chemie*. July 6, 1915. See also pages 294-295.

SUBSTANCE	PROPERTIES
U	Sol. in excess of am. carb. Nitrate soluble in ether and acetone. Atomic weight, 238.2. Half-decay period, $5 \times 10^9$ years. Gives off $\alpha$ particles.
UX	Carried down by $\text{BaSO}_4$ . Soluble in HCl. Less volatile than U. Volatile in electric arc. Insoluble in excess of am. carb. Soluble in water and ether. Half-decay period, 24.6 days. Gives off $\beta$ and $\gamma$ particles.
UY	Carried down by barium sulphate, with moist ferric hydrate, and by animal charcoal. Half-decay period, 1.5 days.
Io	Soluble in excess of am. oxalate. Carried down by $\text{H}_2\text{O}_2$ in presence of U salts. Half-decay period, over $2 \times 10^6$ years (?). Gives off $\alpha$ particles.
Ra	Characteristic spectrum. Spontaneously luminous. Analogous to Ba. $\text{RaCl}_2$ and $\text{RaBr}_2$ are less soluble than $\text{BaCl}_2$ and $\text{BaBr}_2$ . Atomic weight, 226.4. Half-decay period, 2000 years. Gives off $\alpha$ and $\beta$ particles.
RaEm (Niton)	One of group of inert gases. Characteristic spectrum. Mol. wt. = 218 Half-decay period, 3.85 days. $\alpha$ particles.
RaA	Behaves as a solid. Deposited on cathode in an electric field. Volatile at 800-900°C. Soluble in strong acids. Half-decay period, 3 min.
RaB	Like RaA. Volatile at 400-600°C. Precipitated by $\text{BaSO}_4$ . Half-decay period, 26.8 min.
RaC	Physically like RaA. Volatile at 800-1300°C. Chemically like RaB. Deposited on Cu and Ni. Perhaps mixture of two products. Half decay period, 30 min. Gives out $\alpha$ , $\beta$ , and $\gamma$ particles.
RaD	Volatile below 1000°C. Soluble in strong acids. Reactions of RaD and $\text{RaE}_1$ analogous to those of Pb. Sometimes known as radiolead. Half-decay period, 40 years. No rays.
$\text{RaE}_1$	Volatile at red heat. Soluble in cold acetic acid. Half-decay period, 5 days.
$\text{RaE}_2$	Not volatile at red heat. Reactions similar to Bi. Half-decay period, 143 days.
$\text{RaF}^a$ (Polonium.)	Volatile toward 1000°C. Deposited from its solutions on Bi, Cu, Sb, Ag, Pt. Carried down by $\text{PbCO}_3$ , and by $\text{SnCl}_2$ with Hg and Te. RaD,

	E <sub>1</sub> , E <sub>2</sub> , and F can be separated by electrolysis. 136 days, breaks down to lead. $\alpha$ particles.
Ac	Produces helium. Precipitated by oxalic acid in acid solutions. Oxalate insoluble in HF; accompanies thorium and rare earths. Unknown period. $\alpha$ particles. Same as emanium.
Rad. Ac	Slightly volatile at high temps. Insoluble in NH <sub>4</sub> OH. Separated from Ac by electrolysis, by fractional precipitation, by ammonia, and by animal charcoal. Half-decay period, 19.5 days. $\alpha$ . Discovered by Hahn.
AcX	Deposited by electrolysis in alkaline solution. Not precipitated by NH <sub>4</sub> OH. 10.5 days. $\alpha$ -rays.
AcEm	Behaves as inert gas. Coef. of diffusion in air 0.11. Condenses at $-120^{\circ}\text{C}$ . Half-decay, 3.9 sec.
AcA	Volatile below $400^{\circ}\text{C}$ . Soluble in NH <sub>4</sub> OH and strong acids. Half-decay, 36 min. Rayless.
AcB	Volatile below $700^{\circ}\text{C}$ . Soluble in NH <sub>4</sub> OH and strong acids. Deposited by electrolysis of active deposits on cathode in HCl. Half-decay, 2 min. $\alpha$ , $\beta$ , $\gamma$ particles.
Th	Volatile in electric arc. Colorless salts not spontaneously phosphorescent. Salts ppd. by NH <sub>4</sub> OH and oxalic acid. Atomic weight, 232.4. Half-decay period $2.4 \times 10^9$ years. $\alpha$ particles.
Rad. Th	Carried down by hydrates, precipitated by NH <sub>4</sub> OH. Separated by Hahn and much more active than thorium, and it may be a small contamination of this element gives out the rays in the thorium transformation and that the thorium transformation is in reality rayless. $\alpha$ rays.
ThX	Soluble in NH <sub>4</sub> OH. Carried down by iron. Deposited by electrolysis in alkalis. 4 days. $\alpha$ particles.
ThEm	Inert gas. Condenses just above $-120^{\circ}\text{C}$ . Half-decay period, 54.5 sec. $\alpha$ particles.
ThA	Volatile under $630^{\circ}\text{C}$ . Soluble in strong acids. 11 hrs.
ThB	Volatile below $730^{\circ}\text{C}$ . Like ThA. Deposited on Ni. Separated from ThA by electrolysis. 55 min. $\alpha$ , $\beta$ , $\gamma$ particles.
ThC	Like ThB. Probably two products.

One gram of radium gives off 0.0328 cal. per sec., and produces  $5.17 \times 10^{-9}$  cc. of helium ( $0^{\circ}$ , 76 cm. pressure) per gram per sec.  
 One gram of radium expels  $1.36 \times 10^{11}$   $\alpha$  particles per minute.

## GROWTH AND DECAY OF RADIUM EMANATION

( $T$  = time  $X$  = fraction of emanation remaining after time,  $T$ .  $Y$  = fraction of equilibrium amount formed in time  $T$ .)

$T$	$X$	$Y$	$T$	$X$	$Y$
0	1.0000	0.0000	5 days	0.4066	0.593
1 hr.	0.9925	0.0075	6 days	0.3396	0.660
2 hr.	0.9851	0.0149	7 days	0.2837	0.716
3 hr.	0.9777	0.0223	8 days	0.2369	0.763
4 hr.	0.9704	0.0296	9 days	0.1979	0.802
5 hr.	0.9632	0.0368	10 days	0.1653	0.834
6 hr.	0.9560	0.0440	11 days	0.1381	0.861
7 hr.	0.9489	0.0511	12 days	0.1153	0.884
8 hr.	0.9418	0.0582	13 days	0.0963	0.903
9 hr.	0.9347	0.0653	14 days	0.0805	0.919
10 hr.	0.9277	0.0723	15 days	0.0672	0.932
11 hr.	0.9208	0.0792	16 days	0.0561	0.943
12 hr.	0.9139	0.0861	17 days	0.0469	0.953
13 hr.	0.9071	0.0929	18 days	0.0392	0.960
14 hr.	0.9003	0.0997	19 days	0.0327	0.967
15 hr.	0.8936	0.1064	20 days	0.0273	0.972
16 hr.	0.8869	0.1131	21 days	0.0228	0.977
17 hr.	0.8803	0.1197	22 days	0.0191	0.980
18 hr.	0.8737	0.1263	23 days	0.0159	0.984
19 hr.	0.8672	0.1328	24 days	0.0133	0.986
20 hr.	0.8607	0.1393	25 days	0.0111	0.988
21 hr.	0.8543	0.1457	26 days	0.0093	0.990
22 hr.	0.8479	0.1521	27 days	0.0078	0.992
23 hr.	0.8416	0.1584	28 days	0.0065	0.993
1 day	0.8353	0.1647	29 days	0.0054	0.994
2 days	0.6977	0.3023	30 days	0.0045	0.995
3 days	0.5827	0.4173	40 days	0.0007	0.999
4 days	0.4868	0.5132	50 days	0.0001	0.999

*Example*—If the emanation formed by the standards, or by any sample, is transferred to the electroscope 3 days and 20 hr. after sealing, the fraction of the equilibrium amount of emanation formed will be:

Value of  $X$  for time  $T$  (3 days) = 0.5827.

Value of  $X$  for time  $T$  (20 hr.) = 0.8607.

Therefore,  $X = 0.5827 \times 0.8607 = 0.5015$ .

## Heats of Formation

Heats of formation are expressed in calories, *i.e.*, the amount of heat necessary to raise 1 gram of water from 10°C. to 11°C. When it is said that the heat of formation of any compound is a certain number of units, it is meant that this number of calories is developed in the production of a mass in grams of the substance equal to its molecular weight, *i.e.*, when we say that



we mean that 12 grams of carbon and 32 of oxygen develop 97,200 cal.

The heat of formation and the heat of decomposition of any substance are the same; *i.e.*, in order to effect the decomposition of a substance an amount of heat must be supplied equal to the amount evolved in the formation.

The heat of combination of the elements, like many others of their properties, follows the periodic law, the relation being thus stated by W. G. MIXTER (*Am. Journ. Sci.*, June, 1914): The heat equivalents of the elements of a subgroup in the series III to VIII are either linear functions of the atomic weights, or the heat of formation of the oxide of the middle member falls below the linear value by a constant amount for each atom of oxygen combined.

## HEAT OF FORMATION OF SILICATES

Starting from	Gram-cal. per molecule	Gram-cal. per gram of silicate formed	Starting from	Gram-cal. per molecule	Gram-cal. per gram of silicate formed
FeO, SiO <sub>2</sub> .....	10,600	80	Fe, Si, O <sub>3</sub> .....	254,600	1,929
MnO, SiO <sub>2</sub> .....	5,400	41	Mn, Si, O <sub>3</sub> .....	276,300	2,109
BaO, SiO <sub>2</sub> .....	14,700	69	Ba, Si, O <sub>3</sub> .....	328,100	1,540
CaO, SiO <sub>2</sub> .....	17,850	154	Ca, Si, O <sub>3</sub> .....	329,350	2,839
2CaO, SiO <sub>2</sub> .....	28,300	165	Ca <sub>2</sub> , Si, O <sub>4</sub> .....	471,300	2,740
3CaO, SiO <sub>2</sub> .....	28,550	125	Ca <sub>3</sub> , Si, O <sub>5</sub> .....	603,050	2,845
SrO, SiO <sub>2</sub> .....	17,900	110	Sr, Si, O <sub>3</sub> .....	329,100	2,019
Al <sub>2</sub> O <sub>3</sub> , 2SiO <sub>2</sub> .....	14,900	67	Al <sub>2</sub> , Si <sub>2</sub> , O <sub>7</sub> .....	767,500	3,457
3CaO, Al <sub>2</sub> O <sub>3</sub> , 2SiO <sub>2</sub> .....	33,500	86	Ca <sub>3</sub> , Al <sub>2</sub> , Si <sub>2</sub> , O <sub>10</sub> .....	1,195,550	3,065
3H <sub>2</sub> O, Al <sub>2</sub> O <sub>3</sub> , 2SiO <sub>2</sub> .....	43,800	170	H <sub>2</sub> , Al <sub>2</sub> , Si <sub>2</sub> , O <sub>9</sub> .....	927,420	3,595
Li <sub>2</sub> O, SiO <sub>2</sub> .....	65,100	720	Li <sub>2</sub> , Si <sub>2</sub> , O <sub>3</sub> .....	347,100	3,856
Na <sub>2</sub> O, SiO <sub>2</sub> .....	45,200	370	Na <sub>2</sub> , Si, O <sub>3</sub> .....	326,100	2,673
CaO, Al <sub>2</sub> O <sub>3</sub> .....	450	3	Ca, Al <sub>2</sub> , O <sub>4</sub> .....	524,550	3,220
2CaO, Al <sub>2</sub> O <sub>3</sub> .....	3,300	15	Ca <sub>2</sub> , Al <sub>2</sub> , O <sub>5</sub> .....	658,900	3,079
3CaO, Al <sub>2</sub> O <sub>3</sub> .....	2,950	11	Ca <sub>3</sub> , Al <sub>2</sub> , O <sub>6</sub> .....	789,050	2,922
SiO <sub>2</sub> 35.5, FeO, 39.7, MnO, 1.0, CaO 11.4, MgO 2.7, Al <sub>2</sub> O <sub>3</sub> 0.2, Cu 0.42, S 0.42 per cent. ....	.....	133	.....	.....	.....
2FeO, SiO <sub>2</sub> .....	22,236	109	Fe <sub>2</sub> , Si, O <sub>4</sub> .....	333,636	1,637
FeO 70.80, SiO <sub>2</sub> 29.20 per cent. ....	.....	.....	.....	.....	.....
FeO 57.58, CaO 12.00, SiO <sub>2</sub> 30.42 per cent. ....	.....	140	.....	.....	.....
FeO 40.30, CaO 28.00, SiO <sub>2</sub> 31.70 per cent. ....	.....	193	.....	.....	.....

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## HEAT OF FORMATION OF OXIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Mg, O...	24 + 16 = 40	143,400	148,800
Ba, O.....	137 + 16 = 153	133,400	161,500
Ca, O.....	40 + 16 = 56	131,500	149,600
Sr, O.....	88 + 16 = 104	131,200	158,400
Al <sub>2</sub> , O <sub>3</sub> ...	54 + 48 = 102	392,600	
Ti, O <sub>2</sub> ...	48 + 32 = 80	218,500	
Na <sub>2</sub> , O.....	46 + 16 = 62	100,900	155,900
K <sub>2</sub> , O.....	78 + 16 = 94	98,200	165,200
Th, O <sub>2</sub> ...	232 + 32 = 264	326,000	
Si, O <sub>2</sub> ...	28 + 32 = 60	180,000	180,000
Mn, O.....	55 + 16 = 71	90,900	
B <sub>2</sub> , O <sub>3</sub> ...	22 + 48 = 70	272,600	279,900
Zn, O.....	65 + 16 = 81	84,800 <sup>1</sup>	82,680
Mn <sub>2</sub> , O <sub>4</sub> ...	165 + 64 = 229	328,000	
P <sub>2</sub> , O <sub>5</sub> ...	62 + 80 = 142	365,300	405,000
Sn, O.....	118 + 16 = 134	70,700	
Sn, O <sub>2</sub> ...	118 + 32 = 150	141,300	
CO, O.....	28 + 16 = 44	68,040	73,940
H <sub>2</sub> , O.....	2 + 16 = 18	70,400 solid	
	2 + 16 = 18	69,000 liquid	
	2 + 16 = 18	58,060 gas	
H <sub>2</sub> O <sub>2</sub> .....	2 + 32 = 34		45,000
Fe <sub>2</sub> , O <sub>3</sub> ...	168 + 64 = 232	270,800	
Cd, O.....	112 + 16 = 128	66,300	
Fe, O.....	56 + 16 = 72	65,700	
Fe <sub>2</sub> , O <sub>4</sub> ...	112 + 48 = 160	195,600	
Co, O.....	59 + 16 = 75	64,100	
Mn, O <sub>2</sub> ...	55 + 32 = 87	125,300	
Ni, O.....	58.5 + 16 = 74.5	61,500	
Sb <sub>2</sub> , O <sub>3</sub> ...	240 + 48 = 288	166,900	
As <sub>2</sub> , O <sub>3</sub> ...	150 + 48 = 198	156,400	148,900
Pb, O.....	207 + 16 = 223	50,800	
C, O <sub>2</sub> .....	12 + 32 = 44	97,200 gas	103,100
Bi <sub>2</sub> , O <sub>3</sub> ...	418 + 48 = 466	136,000	171,000
Sb <sub>2</sub> , O <sub>4</sub> ...	240 + 80 = 320	221,200	
As <sub>2</sub> , O <sub>4</sub> ...	150 + 80 = 230	219,400	225,400
Cu <sub>2</sub> , O.....	127.2 + 16 = 143.2	43,800	
Tl <sub>2</sub> , O.....	408 + 16 = 424	42,800	39,700
Cu, O.....	63.6 + 16 = 79.6	37,700	
Ba, O <sub>2</sub> ...	137 + 32 = 169	145,500	
S, O <sub>2</sub> .....	32 + 32 = 64	69,260 gas	77,600
Pb, O <sub>2</sub> ...	207 + 32 = 239	63,400	
S, O <sub>3</sub> .....	32 + 48 = 80	91,900	141,000
Tl <sub>2</sub> , O <sub>3</sub> ...	408 + 48 = 456	87,600	
C, O.....	12 + 16 = 28	29,160 gas	
Hg <sub>2</sub> , O.....	400 + 16 = 416	22,200	
Hg, O.....	200 + 16 = 216	21,500	
Te, O <sub>2</sub> ...	125.5 + 32 = 157.5		78,300
Pd, O.....	106 + 16 = 122	21,000	
Pt, O.....	195 + 16 = 211	17,000	
Ag <sub>2</sub> , O.....	216 + 16 = 232	7,000	
Au <sub>2</sub> , O <sub>3</sub> ...	394 + 48 = 442	-11,500	
N <sub>2</sub> , O.....	28 + 16 = 44	-19,000	
N, O.....	14 + 16 = 30	-21,600	
N <sub>2</sub> , O <sub>3</sub> ...	28 + 48 = 76	-21,400	
N, O <sub>2</sub> (at 22°)	14 + 32 = 46	-1,700	
N, O <sub>2</sub> (at 150°)	14 + 32 = 46	-7,450	
N <sub>2</sub> O <sub>3</sub> .....	28 + 70 = 98	1,190	3,600
Ca <sub>2</sub> O.....	266 + 16 = 282	100,000	
Li <sub>2</sub> O.....	14 + 16 = 30	140,000	
Rb <sub>2</sub> O.....	171 + 16 = 187	94,900	
W, O <sub>3</sub> .....	184 + 48 = 232	192,000	
V <sub>2</sub> , O <sub>5</sub> .....	102 + 80 = 182	441,000	

<sup>1</sup> 42,740 at 1125°C.



HEAT OF FORMATION OF OXIDES (*Continued*)

Formula	Molecular weights	Molecular heat of formation	In dilute solution
V <sub>2</sub> O <sub>5</sub> .....	102+48=150	353,200	287,000
V <sub>2</sub> O <sub>4</sub> .....	51+16=67	104,300	
Mo <sub>2</sub> O <sub>3</sub> ...	96+32=128	132,000	
Cr <sub>2</sub> O <sub>3</sub> ...	104+48=152	266,000	
Zr <sub>2</sub> O <sub>3</sub> ...	91+32=123	177,500	
Tl <sub>2</sub> O <sub>3</sub> ...	140+32=172	232,100	
Ta <sub>2</sub> O <sub>5</sub> ...	181.5+32=213.5	301,500	

HEATS OF FORMATION OF MIXTURES OF SiO<sub>2</sub>, CaO, AND ANHYDROUS KAOLIN

The kaolin used in these experiments was: SiO<sub>2</sub>, 53.58 per cent., Al<sub>2</sub>O<sub>3</sub>, 43.40, Fe<sub>2</sub>O<sub>3</sub>, 1.25. The difference between the sum of the Al<sub>2</sub>O<sub>3</sub> and CaO and 100% is the SiO<sub>2</sub>.

Al <sub>2</sub> O <sub>3</sub> per cent. CaO per cent.	2	10	20	30
10	...	...	+ 19 2	+ 1.7
20	...	+ 42 8	+ 47 9	+49.9
30	+ 76.1	+ 69.7	+ 82 3	+73.0
40	+103.2	+109.0	+106.5	.....
50	+150.6	+135.8	+137.8	.....
60	+154.0	+180.4	.....	.....

<sup>1</sup> Revue de Metallurgie, 1913, p. 673.

## HEAT OF FORMATION OF HYDROXIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Li, O, H...	7+16+1=24	112,300	118,110
Mg, O <sub>2</sub> , H <sub>2</sub> ...	24+32+2=58	217,800	
Sr, O <sub>2</sub> , H <sub>2</sub> ...	88+32+2=122	217,300	227,400
Ca, O <sub>2</sub> , H <sub>2</sub> ...	40+32+2=74	237,000	239,000
K, O, H...	39+16+1=56	104,600	117,100
Na, O, H...	23+16+1=40	102,700	112,500
N, H <sub>4</sub> , O, H...	14+16+5=35	88,800	90,000
Al, O <sub>2</sub> , H <sub>2</sub> ...	27+48+3=78	301,300	
H, O, H...	1+16+1=18	{ 70,400 solid { 69,000 liquid { 58,060 gas	
Tl, O, H...	204+16+1=221	57,400	54,300
Bi, O <sub>2</sub> , H <sub>2</sub> ...	209+48+3=260	171,700	
Zn, O <sub>2</sub> , H <sub>2</sub> ...	65+32+2=99	159,000	
Te, O <sub>2</sub> , H <sub>2</sub> ...	127+32+2=161	78,300	
Tc, O <sub>2</sub> , H <sub>2</sub> ...	127+48+3=178	99,500	
Se, O <sub>2</sub> , H <sub>2</sub> ...	79+48+2=129	141,000	124,000
Se, O <sub>4</sub> , H <sub>2</sub> ...	79+64+2=141	130,000	200,000
Tl, O <sub>2</sub> , H <sub>2</sub> ...	204+48+3=255	43,800	
Ba, O <sub>2</sub> , H <sub>2</sub> ...	137+32+2=171	228,000	
Cd, O <sub>2</sub> , H <sub>2</sub> ...	112+32+2=146	133,500	
Cs, O, H...	133+16+1=150	101,300	
Rb, O, H...	85.5+16+1=102.5	102,000	
Fe, O <sub>2</sub> , H <sub>2</sub> ...	56+48+3=107	197,000	
Ni, O <sub>2</sub> , H <sub>2</sub> ...	59+32+2=103	130,000	
Ni, O <sub>2</sub> , H <sub>2</sub> ...	59+48+3=110	197,000	
S, O <sub>4</sub> , H <sub>2</sub> ...	32+64+2=98	190,000	269,000
S, O <sub>2</sub> , H <sub>2</sub> ...	32+48+2=82	145,000	

## HEAT OF FORMATION OF METALLIC HYDRIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Sr, H <sub>2</sub> . . . . .	87 + 2 = 89	38,400	
Ba, H <sub>2</sub> . . . . .	137 + 2 = 139	37,500	
Pt <sub>10</sub> , H . . . . .	1950 + 1 = 1951	14,200	
Pd <sub>10</sub> , H . . . . .	1590 + 1 = 1591	4,600	
Si, H <sub>4</sub> . . . . .	28 + 4 = 32	1,194	
N, H <sub>3</sub> . . . . .	3 + 14 = 17	10,975 gas	19,450
Li, H . . . . .	7 + 1 = 8	22,500	
N, H <sub>3</sub> . . . . .	3 + 14 = 17	15,850 liquid	19,450
Ca, H <sub>2</sub> . . . . .	40 + 2 = 42	45,900	

## HEAT OF FORMATION OF CYANIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Ca, C <sub>2</sub> , N <sub>2</sub> . . . . .	40 + 24 + 28 = 92	.....	41,650
K, C, N . . . . .	39 + 12 + 14 = 65	33,450	30,250
Na, C, N . . . . .	23 + 12 + 14 = 49	25,950	25,450
K, Ag, C <sub>2</sub> , N <sub>2</sub> . . . . .	39 + 108 + 24 + 28 = 199	13,700	5,350
Fe <sub>7</sub> , C <sub>18</sub> , N <sub>18</sub> . . . . .	392 + 216 + 252 = 860	-256,700	
Zn, C <sub>2</sub> , N <sub>2</sub> . . . . .	65 + 24 + 28 = 117	-24,550	
Cd, C <sub>2</sub> , N <sub>2</sub> . . . . .	112 + 24 + 28 = 164	-31,850	
Cu, C <sub>2</sub> , N <sub>2</sub> . . . . .	63.6 + 24 + 28 = 115.6	-20,375	
Pd, C <sub>2</sub> , N <sub>2</sub> . . . . .	106 + 24 + 28 = 158	-49,250	
H, C, N . . . . .	1 + 12 + 14 = 27	-27,150 (gas)	-21,050
Hg, C <sub>2</sub> , N <sub>2</sub> . . . . .	200 + 24 + 28 = 252	-59,150	
(Au, C <sub>2</sub> , N <sub>2</sub> ) . . . . .	197 + 24 + 28 = 249	-53,900	

## HEAT OF FORMATION OF CYANATES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
K, C, N, O . . . . .	39 + 12 + 14 + 16 = 81	100,100	95,000
Na, C, N, O . . . . .	23 + 12 + 14 + 16 = 65	97,500	92,400
Ag, C, N, O . . . . .	108 + 12 + 14 + 16 = 150	23,700	

## HEAT OF FORMATION OF TELLURIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Zn, Te . . . . .	65 + 126 = 191	31,000	.....
Cd, Te . . . . .	112 + 126 = 238	16,600	.....
Co, Te . . . . .	59 + 126 = 185	13,000	.....
Fe, Te . . . . .	56 + 126 = 182	12,000	.....
Ni, Te . . . . .	58.5 + 126 = 184.5	11,600	.....
Tl <sub>2</sub> , Te . . . . .	408 + 126 = 534	10,600	.....
Cu <sub>2</sub> , Te . . . . .	127.2 + 126 = 253.2	8,200	.....
Pb, Te . . . . .	207 + 126 = 333	6,200	.....
H <sub>2</sub> , Te . . . . .	2 + 126 = 128	-34,900 (gas)	.....

## HEAT OF FORMATION OF SELENIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Li <sub>2</sub> , Se...	14 + 79 = 93	83,000	93,700
K <sub>2</sub> , Se...	78 + 79 = 157	79,600	87,900
Ba, Se...	137 + 79 = 216	88,400	
Sr, Se...	88 + 79 = 167	90,400	102,200
Ca, Se...	40 + 79 = 119	88,500	
Na <sub>2</sub> , Se...	46 + 79 = 125	69,500	88,400
Zn, Se...	65 + 79 = 144	30,300	
Cd, Se...	112 + 79 = 191	23,700	
Mn, Se...	55 + 79 = 134	22,400	
N, H <sub>2</sub> , Se	14 + 5 + 79 = 98	17,800	12,800
Cu, Se....	63.6 + 79 = 142.6	17,300	
Pb, Se...	207 + 79 = 286	17,000	
Fe, Se...	56 + 79 = 135	15,200	
Ni, Se....	58.5 + 79 = 137.5	14,700	
Co, Se...	59 + 79 = 138	13,900	
Ti <sub>2</sub> , Se...	408 + 79 = 487	13,400	
Cu <sub>2</sub> , Se....	127.2 + 79 = 206.2	8,000	
Hg, Se...	200 + 79 = 279	6,300	
Ag <sub>2</sub> , Se...	216 + 79 = 295	2,000	
H <sub>2</sub> , Se...	2 + 79 = 81	-15,800 (gas)	-13,400
N, Se...	14 + 79 = 93	-42,800	

## HEAT OF FORMATION OF SULPHATES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
K <sub>2</sub> , S, O <sub>4</sub> ...	78 + 32 + 64 = 174	344,300	337,700
Ba, S, O <sub>4</sub> ...	137 + 32 + 64 = 233	315,000	341,000
Li <sub>2</sub> , S, O <sub>4</sub> ...	14 + 32 + 64 = 110	333,500	339,600
Sr, S, O <sub>4</sub> ...	88 + 32 + 64 = 184	311,000	341,000
Na <sub>2</sub> , S, O <sub>4</sub> ...	46 + 32 + 64 = 142	328,100	328,500
Ca, S, O <sub>4</sub> ...	40 + 32 + 64 = 136	317,400	321,800
Mg, S, O <sub>4</sub> ...	24 + 32 + 64 = 120	300,900	321,100
Al <sub>2</sub> , S <sub>3</sub> , O <sub>12</sub>	54 + 96 + 192 = 342		879,700
N <sub>2</sub> , H <sub>2</sub> , S, O <sub>4</sub> ...	28 + 8 + 32 + 64 = 132	283,500	281,100
Mn, S, O <sub>4</sub> ...	55 + 32 + 64 = 151	249,400	263,200
Zn, S, O <sub>4</sub> ...	65 + 32 + 64 = 161	229,600	248,000
Fe, S, O <sub>4</sub> ...	56 + 32 + 64 = 152	227,000	234,900 <sup>1</sup>
Co, S, O <sub>4</sub> ...	59 + 32 + 64 = 155	225,000	228,900
Ni, S, O <sub>4</sub> ...	58.5 + 32 + 64 = 154.5	228,000	228,700
Fe <sub>2</sub> , S <sub>3</sub> , O <sub>12</sub>	112 + 96 + 192 = 400		640,000
Ti <sub>2</sub> , S, O <sub>4</sub> ...	408 + 32 + 64 = 504	221,800	213,500
Cd, S, O <sub>4</sub> ...	112 + 32 + 64 = 208	219,900	231,600
Pb, S, O <sub>4</sub> ...	207 + 32 + 64 = 303	215,700	
H <sub>2</sub> , S, O <sub>4</sub> ...	2 + 32 + 64 = 98	192,200	210,200
Cu, S, O <sub>4</sub> ...	63.6 + 32 + 64 = 159.6	181,700	197,500
Hg <sub>2</sub> , S, O <sub>4</sub> ...	400 + 32 + 64 = 496	175,000	
Ag <sub>2</sub> , S, O <sub>4</sub> ...	216 + 32 + 64 = 312	167,100	162,600
Hg, S, O <sub>4</sub> ...	200 + 32 + 64 = 296	165,100	
Co, S, O <sub>4</sub> ·7H <sub>2</sub> O	59 + 32 + 64 + 126 = 281		234,000
N <sub>2</sub> , H <sub>2</sub> , S <sub>1</sub> , O <sub>4</sub> ...	28 + 8 + 32 + 64 = 132	283,500	281,100
Rb <sub>2</sub> , S, O <sub>4</sub> ....	171 + 32 + 64 = 267	344,700	
Cs <sub>2</sub> , S, O <sub>4</sub> ....	266 + 32 + 64 = 362	349,700	

<sup>1</sup> 240,000 for FeSO<sub>4</sub>·7H<sub>2</sub>O.

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## HEAT OF FORMATION OF SULPHIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
$\text{Li}_2\text{S}$	$14 + 32 = 46$	.....	115,400
$\text{K}_2\text{S}$	$78 + 32 = 110$	103,500	113,500
$\text{BaS}$	$137 + 32 = 169$	102,900	109,800
$\text{SrS}$	$88 + 32 = 120$	99,300	106,700
$\text{CaS}$	$40 + 32 = 72$	94,300	100,600
$\text{Na}_2\text{S}$	$46 + 32 = 78$	89,300	104,300
$\text{MgS}$	$24 + 32 = 56$	79,400	
$\text{K}_2\text{S}_2$	$39 + 64 = 103$	59,300	59,700
$\text{Na}_2\text{S}_2$	$23 + 64 = 87$	49,500	54,400
$\text{MnS}$	$55 + 32 = 87$	45,600	
$\text{ZnS}$	$65 + 32 = 97$	43,000	
$\text{Al}_2\text{S}_3$	$54 + 96 = 150$	126,400	
$\text{N}_2\text{H}_4\text{S}$	$14 + 5 + 32 = 51$	40,000	36,700
$\text{CdS}$	$112 + 32 = 144$	34,400	
$\text{BaS}_2$	$22 + 96 = 118$	75,800	
$\text{FeS}$	$56 + 32 = 88$	24,000	
$\text{CoS}$	$59 + 32 = 91$	21,900	
$\text{TiS}_2$	$204 + 32 = 236$	21,600	
$\text{Cu}_2\text{S}$	$127 \times 2 + 32 = 159 \times 2$	20,300	
$\text{PbS}$	$207 + 32 = 239$	20,200	
$\text{SiS}_2$	$28 + 64 = 92$	40,000	
$\text{NiS}$	$58 + 32 = 90$	19,500	
$\text{Sb}_2\text{S}_3$	$240 + 96 = 336$	34,400	
$\text{HgS}$	$200 + 32 = 232$	10,600	
$\text{Cu}_2\text{S}$	$63 \times 2 + 32 = 95 \times 2$	10,100	
$\text{H}_2\text{S}$	$2 + 32 = 34$	4,800 gas <sup>1</sup>	9,500
$\text{Ag}_2\text{S}$	$216 + 32 = 248$	3,000	
$\text{CS}_2$	$12 + 64 = 76$	{ -25,720 gas -19,610 liquid	
$\text{IS}$	$127 + 32 = 159$	9,000	

<sup>1</sup> Molecular heat of combustion of  $\text{H}_2\text{S}$  122,500 cal, and heat of combustion of 1 cu meter  $\text{H}_2\text{S}$  = 5,513 cal.

## HEAT OF FORMATION OF BI-SULPHATES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
$\text{K}_2\text{H}_2\text{S}_2\text{O}_8$	$39 + 1 + 32 + 64 = 136$	276,100	272,900
$\text{Na}_2\text{H}_2\text{S}_2\text{O}_8$	$23 + 1 + 32 + 64 = 120$	269,100	268,300
$\text{NH}_4\text{H}_2\text{S}_2\text{O}_8$	$14 + 5 + 32 + 64 = 115$	244,600	245,100
$\text{H}_2\text{F}_2\text{S}_2\text{O}_8$	$1 + 1 + 32 + 64 = 98$	192,200	210,200

## HEAT OF FORMATION OF SULPHITES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
$\text{S}_2\text{O}_3\text{K}_2$	$32 + 48 + 78 = 158$	.....	272,600
$\text{S}_2\text{O}_3\text{Na}_2$	$32 + 48 + 46 = 126$	.....	261,000

## HEAT OF FORMATION OF NITRATES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
K, N, O <sub>3</sub> .....	39+14+ 48 = 101	119,000	110,700
Na, N, O <sub>3</sub> .....	23+14+ 48 = 85	110,700	106,000
Zn, N <sub>2</sub> , O <sub>6</sub> .....	65+28+ 96 = 187	.....	131,700
Pb, N <sub>2</sub> , O <sub>6</sub> .....	207+28+ 96 = 331	105,400	98,200
Cu, N <sub>2</sub> , O <sub>6</sub> .....	63.5+28+ 96 = 187.5	.....	81,300
H, N, O <sub>3</sub> .....	1+14+ 48 = 63	34,400 gas	48,800
Ag, N, O <sub>3</sub> .....	108+14+ 48 = 170	28,700	23,000
Ca, N <sub>2</sub> , O <sub>6</sub> <sup>1</sup> .....	40+28+ 96 = 164	202,000	.....
Co, N <sub>2</sub> , O <sub>6</sub> ·6H <sub>2</sub> O <sup>1</sup> .....	59+28+96+108 = 283	.....	119,000
LiNO <sub>2</sub> <sup>1</sup> .....	7+14+ 48 = 69	112,000	.....
N, H <sub>4</sub> , N, O <sub>3</sub> <sup>1</sup> .....	14+ 4+14+ 48 = 80	88,600	82,400

## HEAT OF FORMATION OF NITRIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
C <sub>2</sub> , N <sub>2</sub>	24+28 = 52	{ - 73,000 gas 10,975 gas 15,850 liquid	- 68,300
H <sub>3</sub> , N ..	3+14 = 17		19,450
Ba <sub>3</sub> , N <sub>2</sub>	411+28 = 439	149,400	10,450
Li <sub>3</sub> , N	21+14 = 35	49,500	.....
K, H <sub>3</sub> , N ..	39+3+14 = 56	30,700	.....
Ca <sub>3</sub> , N <sub>2</sub> ..	120+28 = 148	111,200	.....
Mg <sub>3</sub> , N <sub>2</sub> ..	72+28 = 100	118,500	.....

## HEAT OF FORMATION OF FERRO AND FERRICYANIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
K <sub>4</sub> , Fe, C <sub>6</sub> , N <sub>6</sub>	156+56+72+84 = 368	131,900	119,200
H <sub>4</sub> , Fe, C <sub>6</sub> , N <sub>6</sub>	4+56+72+84 = 216	- 102,000	- 101,500
K <sub>2</sub> , Fe, C <sub>6</sub> , N <sub>6</sub> ..	117+56+72+84 = 329	48,900	34,500
H <sub>2</sub> , Fe, C <sub>6</sub> , N <sub>6</sub>	3+56+72+84 = 215	.....	- 127,400

## HEAT OF FORMATION OF PHOSPHIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Mn <sub>3</sub> , P <sub>2</sub> ..	165+62 = 227	70,900	.....
H <sub>3</sub> , P ..	3+31 = 34	4,900	.....
Fe, P ..	56+39 = 95	nearly 0	.....

# 352 METALLURGISTS AND CHEMISTS' HANDBOOK

## PHOSPHATES AND MISCELLANEOUS ACIDS

Formula	Molecular weights	Molecular heat of formation	In dilute solution
$\text{Ca}_3, \text{P}_2, \text{O}_8 \dots$	$120 + 62 + 128 = 310$	919,200	
$\text{Mg}_3, \text{P}_2, \text{O}_8 \dots$	$72 + 62 + 128 = 262$	910,600	
$\text{Na}_3, \text{P}, \text{O}_4 \dots$	$69 + 31 + 64 = 164$	452,400	
$\text{H}_3, \text{P}, \text{O}_4 \dots$	$3 + 31 + 64 = 98$	.....	302,000
$\text{H}, \text{Br}, \text{O}_3 \dots$	$1 + 80 + 48 = 129$	.....	12,500
$\text{H}, \text{Cl}, \text{O}_3 \dots$	$1 + 35.5 + 48 = 84.5$	.....	22,000
$\text{H}, \text{Cl}, \text{O}_4 \dots$	$1 + 35.5 + 64 = 100.5$	.....	39,100
$\text{H}, \text{I}, \text{O}_3 \dots$	$1 + 127 + 48 = 176$	.....	57,700
$\text{H}_3, \text{P}, \text{O}_3 \dots$	$3 + 31 + 48 = 82$	.....	228,800

## HEAT OF FORMATION OF CHLORIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
$\text{K}, \text{Cl}$	$39 + 35.5 = 74.5$	105,700	101,200
$\text{Ba}, \text{Cl}_2$	$137 + 71 = 208$	197,100	198,300
$\text{Be}, \text{Cl}_2$	$9 + 71 = 80$	155,000	199,500
$\text{Na}, \text{Cl}$	$23 + 35.5 = 58.5$	97,900	96,600
$\text{Li}, \text{Cl}$	$7 + 35.5 = 42.5$	93,900	102,300
$\text{Sr}, \text{Cl}_2$	$88 + 71 = 159$	184,700	195,850
$\text{Ca}, \text{Cl}_2$	$40 + 71 = 111$	169,900	187,400
$\text{N}, \text{H}_4, \text{Cl}$	$14 + 4 + 35.5 = 53.5$	76,800	72,800
$\text{Mg}, \text{Cl}_2$	$24 + 71 = 95$	151,200	187,100
$\text{S}, \text{Cl}_2$	$28 + 142 = 170$	128,800 gas	
$\text{Al}, \text{Cl}_3$	$27 + 106.5 = 133.5$	161,800	238,100
$\text{Mn}, \text{Cl}_2$	$55 + 71 = 126$	112,600	128,000
$\text{Zn}, \text{Cl}_2$	$65 + 71 = 136$	97,400	113,000
$\text{Ti}, \text{Cl}$	$204 + 35.5 = 239.5$	48,600	38,400
$\text{Cd}, \text{Cl}_2$	$112 + 71 = 183$	93,700	96,400
$\text{Pb}, \text{Cl}_2$	$207 + 71 = 278$	85,500	77,900
$\text{Fe}, \text{Cl}_2$	$56 + 71 = 127$	82,200	100,100
$\text{Sn}, \text{Cl}_2$	$118 + 71 = 189$	80,900	
$\text{Co}, \text{Cl}_2$	$59 + 71 = 130$	76,700	95,000
$\text{Ni}, \text{Cl}_2$	$58.5 + 71 = 129.5$	74,700	93,900
$\text{Cu}, \text{Cl}$	$63.5 + 35.5 = 99$	35,400	
$\text{Sn}, \text{Cl}_4$	$118 + 142 = 260$	129,800 liquid	
$\text{Fe}, \text{Cl}_3$	$56 + 106.5 = 162.5$	96,150	127,850
$\text{Hg}, \text{Cl}$	$200 + 35.5 = 235.5$	31,320	
$\text{Sb}, \text{Cl}_3$	$120 + 106.5 = 226.5$	91,400	
$\text{Bi}, \text{Cl}_3$	$209 + 106.5 = 315.5$	90,800	
$\text{B}, \text{Cl}_3$	$11 + 106.5 = 117.5$	89,100 gas	93,400
$\text{Ag}, \text{Cl}$	$108 + 35.5 = 143.5$	29,900	
$\text{Hg}, \text{Cl}_2$	$200 + 71 = 271$	53,300	50,300
$\text{Cu}, \text{Cl}_2$	$63.5 + 71 = 134.5$	51,400	62,500
$\text{As}, \text{Cl}_3$	$75 + 106.5 = 181.5$	71,500	
$\text{H}, \text{Cl}$	$1 + 35.5 = 36.5$	22,000	39,400
$\text{Sb}, \text{Cl}_5$	$120 + 177.5 = 297.5$	104,500 liquid	
$\text{Pd}, \text{Cl}_2$	$106 + 71 = 177$	40,500	
$\text{Pt}, \text{Cl}_4$	$195 + 142 = 337$	60,200	79,800
$\text{Au}, \text{Cl}_3$	$197 + 106.5 = 303.5$	22,800	27,200
$\text{Au}, \text{Cl}$	$197 + 35.5 = 232.5$	5,800	
$\text{P}, \text{Cl}_3$	$31 + 106.5 = 137.5$	69,700	
$\text{Rb}, \text{Cl}$	$85.5 + 35.5 = 121$	105,900	
$\text{Cs}, \text{Cl}$	$133 + 35.5 = 168.5$	109,900	
$\text{Si}, \text{Cl}_4$	$28 + 141.7 = 169.7$	121,800 gas	
$\text{Th}, \text{Cl}_4$	$232 + 141.7 = 373.7$	300,200	
$\text{V}, \text{Cl}_5$	$51 + 106.5 = 157.5$	373,800	

## HEAT OF FORMATION OF BROMIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Na, Br...	23 + 80 = 103	Liquid bromine 79,450	
K, Br.	46 + 80 = 126	99,050	
Al, Br <sub>3</sub>	27 + 240 = 267	120,600	207,500
Zn, Br <sub>2</sub>	65 + 160 = 225	78,200	93,200
Cd, Br <sub>2</sub>	112 + 160 = 272	76,200	77,200
Pb, Br <sub>2</sub>	207 + 160 = 367	69,000	59,000
Sn, Br <sub>2</sub>	118 + 160 = 278	63,000	
Cu, Br <sub>2</sub> .....	63 + 80 = 143	26,000	
Sn, Br <sub>4</sub> ..	118 + 320 = 438	{ 101,400 (solid) 98,400 (liquid)	118,000
Hg, Br..	200 + 80 = 280	24,500	
Ag, Br (cryst)...	108 + 80 = 188	23,700	
Sb, Br <sub>3</sub> ....	120 + 240 = 360	64,900	
Cu, Br <sub>2</sub> .	63 + 160 = 223	34,800	53,000
Pt, Br <sub>4</sub> ..	195 + 320 = 515	42,400	52,200
Au, Br <sub>3</sub>	197 + 240 = 437	13,400	8,400
Au, Br <sub>2</sub> ....	197 + 160 = 357	1,000	
H, Br. . . . .	1 + 80 = 81	8,400	28,600

## HEAT OF FORMATION OF FLUORIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Sr, F <sub>2</sub> . . .	88 + 38 = 126	289,000	
Ba, F <sub>2</sub> .	137 + 38 = 175	224,000	221,500
Li, F	7 + 19 = 26		116,880
K, F	39 + 19 = 58	110,000	113,600
Ca, F <sub>2</sub>	40 + 38 = 78	216,450	
Mg, F <sub>2</sub>	24 + 38 = 62	209,500	
Na, F	23 + 19 = 42	109,720	109,120
N, H <sub>4</sub> , F.	14 + 4 + 19 = 37	101,250	99,750
Al, F <sub>3</sub>	27 + 57 = 84		275,220
B, F <sub>3</sub>	11 + 57 = 68		219,345
Mn, F <sub>2</sub>	55 + 38 = 93		153,310
Zn, F <sub>2</sub>	65 + 38 = 103		138,220
Si, F <sub>4</sub>	28 + 76 = 104	275,920 gas	
Fe, F <sub>2</sub>	56 + 38 = 94		125,220
Cd, F <sub>2</sub>	112 + 38 = 150		121,720
Co, F <sub>2</sub> . . .	59 + 38 = 97		120,340
Ni, F <sub>2</sub> . . .	58.5 + 38 = 96.5		118,980
Fe, F <sub>3</sub> . . .	56 + 57 = 113		164,940
Tl, F . . . . .	204 + 19 = 223		54,405
Pb, F <sub>2</sub> . . .	207 + 38 = 245	101,600	
H, F . . . . .	1 + 19 = 20	38,500 gas	50,300 <sup>1</sup>
Sb, F <sub>3</sub> . . .	120 + 57 = 177		136,680
Cu, F <sub>2</sub>	63.6 + 38 = 101.6		88,160
Ag, F . . . . .	108 + 19 = 127	22,070	25,470

<sup>1</sup> Other authorities, 73,500.

## HEAT OF FORMATION OF IODIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Zn, I <sub>2</sub> .....	65 + 254 = 319	49,200	60,600
Cd, I <sub>2</sub> .....	112 + 254 = 366	45,000	44,000
Pb, I <sub>2</sub> .....	207 + 254 = 461	42,000	.....
Cu, I <sub>2</sub> .....	63.5 + 254 = 317.5	16,500	.....
Hg, I <sub>2</sub> .....	200 + 254 = 454	14,200	.....
Ag, I (cryst.)	108 + 127 = 235	14,300	.....
Hg, I <sub>2</sub> (red).	200 + 254 = 454	24,300	.....
Sb, I <sub>3</sub> .....	120 + 381 = 501	29,200	.....
Au, I.....	197 + 127 = 324	-55,000	.....
H, I.....	1 + 127 = 128	- 6,400	13,200
K, I.....	46 + 127 = 173	87,500	.....
Na, I.....	23 + 127 = 150	76,500	.....

## ARSENIDES, ANTIMONIDES, BORATES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
H <sub>3</sub> , As.....	3 + 75 = 78	-44,200 gas	-36,700
H <sub>3</sub> , Sb.....	3 + 120 = 123	-86,800 gas	.....
Na <sub>2</sub> , B <sub>2</sub> , O <sub>7</sub> .....	46 + 44 + 112 = 202	748,100	758,300

## HEAT OF FORMATION OF SILICIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Mn <sub>7</sub> , Si <sub>2</sub> .....	285 + 56 = 441	47,400	.....
H <sub>4</sub> , Si.....	4 + 28 = 32	1,194 gas	.....

## HEAT OF FORMATION OF CARBIDES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Al <sub>4</sub> , C <sub>3</sub> .....	108 + 36 = 144	81,600	.....
Mn <sub>3</sub> , C.....	165 + 12 = 177	12,450	.....
Fe <sub>3</sub> , C.....	168 + 12 = 180	- 4,610	.....
Ca, C.....	40 + 24 = 64	14,600	.....
Li, C.....	7 + 12 = 19	6,850	.....
N <sub>2</sub> , C <sub>2</sub> .....	28 + 24 = 52	-65,500 gas	-70,800
Ag, C.....	108 + 12 = 120	-43,575	.....
Mn <sub>3</sub> , C.....	165 + 12 = 177	10,400	.....
Zr, C.....	91 + 12 = 103	34,800	.....
Si, C.....	28 + 12 = 40	1,435	.....



## HEAT OF FORMATION OF CARBONATES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Ba, C, O <sub>3</sub> .....	137 + 12 + 48 = 197	286,300	
K <sub>2</sub> , C, O <sub>3</sub> ....	78 + 12 + 48 = 138	282,100	288,600
Sr, C, O <sub>3</sub> ...	88 + 12 + 48 = 148	291,400	
Ca, C, O <sub>3</sub> ...	40 + 12 + 48 = 100	289,000	279,300
Na <sub>2</sub> , C, O <sub>3</sub> ...	46 + 12 + 48 = 106	273,700	
Mg, C, O <sub>3</sub> ...	24 + 12 + 48 = 84	269,900	
Mn, C, O <sub>3</sub> ...	55 + 12 + 48 = 115	210,300	
Zn, C, O <sub>3</sub> ...	65 + 12 + 48 = 125	197,500	
Fe, C, O <sub>3</sub> ...	56 + 12 + 48 = 116	187,800	
Cd, C, O <sub>3</sub> ...	112 + 12 + 48 = 172	183,200	
Pb, C, O <sub>3</sub> ...	207 + 12 + 48 = 267	170,000	
Cu, C, O <sub>3</sub> ...	63.6 + 12 + 48 = 123.6	146,100	
Ag <sub>2</sub> , C, O <sub>3</sub> ...	216 + 12 + 48 = 276	123,800	
N, H <sub>4</sub> , H, CO <sub>3</sub>	14 + 4 + 1 + 12 + 48 = 79	205,300	199,000

## HEAT OF FORMATION OF BICARBONATES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
K, H, C, O <sub>3</sub> ...	39 + 1 + 12 + 48 = 100	233,300	228,000
Na, H, C, O <sub>3</sub>	23 + 1 + 12 + 48 = 84	227,000	222,700

## HEAT OF FORMATION OF ALUMINATES

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Ca, Al <sub>2</sub> , O <sub>4</sub> ...	40 + 54 + 64 = 158	524,550	.....
Ca <sub>2</sub> , Al <sub>2</sub> , O <sub>5</sub> ...	80 + 54 + 80 = 214	658,900	.....
Ca <sub>3</sub> , Al <sub>2</sub> , O <sub>6</sub> .....	120 + 54 + 96 = 270	789,050	.....

## HEAT OF FORMATION OF AMALGAMS

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Hg <sub>12</sub> , K.....	2,400 + 39 = 2,439	34,600	25,600
Hg <sub>4</sub> , K.....	800 + 39 = 839	29,700	25,600
Hg <sub>4</sub> , Na.....	1,200 + 23 = 1,223	21,900	19,000
Hg <sub>2</sub> , Au.....	x + 197 = 197 + x	.....	2,580
Hg <sub>2</sub> , Ag.....	x + 108 = 108 + x	.....	2,470

**HEAT OF FORMATION OF HYDROCARBONS**  
(All Formed in State of Gas, Unless Otherwise Specified)

Name	Formula	Molecular weights	Molecular heat of formation	Molecular heat of complete combustion	Heat of combustion	
					1 m. <sup>3</sup> (cal.)	1 ft. <sup>3</sup> B.t.u.
Methane (marsh gas) ..	(C, H <sub>4</sub> )	12 + 4 = 16	22,250	191,070	8,598	966
Ethane (ethylene hydride) ..	(C <sub>2</sub> , H <sub>6</sub> )	24 + 6 = 30	26,650	341,930	15,387	1,728
Propane (propylene hydride) ..	(C <sub>3</sub> , H <sub>8</sub> )	36 + 8 = 44	33,850	489,900	22,050	2,477
Ethylene (olefiant gas) ..	(C <sub>2</sub> , H <sub>4</sub> )	24 + 4 = 28	-11,250	321,770	14,480	1,627
Propylene ..	(C <sub>3</sub> , H <sub>6</sub> )	36 + 6 = 42	-6,050	471,830	21,232	2,385
Toluene ..	(C <sub>7</sub> , H <sub>8</sub> )	84 + 8 = 92	5,650 (liquid)	906,990	.....	.....
Benzene ..	(C <sub>6</sub> , H <sub>6</sub> )	72 + 6 = 78	-750 (liquid)	758,130	.....	.....
Turpentine ..	(C <sub>10</sub> , H <sub>16</sub> )	120 + 16 = 136	-7,950 (gas)	765,330	34,440	3,869
Naphthaline ..	(C <sub>10</sub> , H <sub>8</sub> )	120 + 8 = 128	-1,850 (gas)	1,428,930	64,725	7,271
Anthracene ..	(C <sub>14</sub> , H <sub>10</sub> )	168 + 10 = 178	-19,450 (solid)	1,223,690	.....	.....
Acetylene ..	(C <sub>2</sub> , H <sub>2</sub> )	24 + 2 = 26	-24,050 (liquid)	1,228,290	55,273	6,209
Methyl-alcohol (wood spirit) ..	(C, H <sub>4</sub> , O)	12 + 4 + 16 = 32	-39,050 (solid)	1,690,150	16,437	1,846
Ethyl-alcohol (alcohol)	(C <sub>2</sub> , H <sub>6</sub> , O)	24 + 6 + 16 = 46	65,050 (liquid)	148,270	.....	.....
Acetone ..	(C <sub>3</sub> , H <sub>6</sub> , O)	36 + 6 + 16 = 58	56,650 (gas)	156,670	7,050	799
			73,250 (liquid)	295,330	.....	.....
			63,150 (gas)	305,430	13,744	1,544
			69,650 (liquid)	396,130	.....	.....
			62,150 (gas)	403,630	18,163	2,040

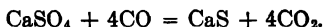
## HEAT OF SOLUTION

Salt dissolved	Calories
$\text{CuSO}_4 \cdot 5\text{H}_2\text{O} \dots$	-2,750
$\text{CdSO}_4 \cdot \frac{8}{3}\text{H}_2\text{O} \dots$	2,660
$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O} \dots$	-4,260
$\text{FeSO}_4 \cdot 7\text{H}_2\text{O} \dots$	- 400
$\text{ZnCl}_2$ in water.	15,630
$\text{ZnSO}_4$ in water.	18,500

## DEHYDRATION OF METALLIC SULPHATES

	Temperature of beginning dehydration, deg. C.	Product formed	Remarks
$\text{FeSO}_4 + 7\text{H}_2\text{O} \dots$	21	$\text{FeSO}_4 + 4\text{H}_2\text{O} \dots$	Slight apple green.
$\text{FeSO}_4 + 4\text{H}_2\text{O} \dots$	80	$\text{FeSO}_4 + \text{H}_2\text{O} \dots$	White
$\text{FeSO}_4 + \text{H}_2\text{O} \dots$	406	$\text{Fe}_2\text{O}_3 + 2\text{SO}_3 \dots$	Yellowish brown.
$\text{Al}_2(\text{SO}_4)_3 + 16\text{H}_2\text{O} \dots$	51	$\text{Al}_2(\text{SO}_4)_3 + 13\text{H}_2\text{O} \dots$	White.
$\text{Al}_2(\text{SO}_4)_3 + 13\text{H}_2\text{O} \dots$	82	$\text{Al}_2(\text{SO}_4)_3 + 10\text{H}_2\text{O} \dots$	White.
$\text{Al}_2(\text{SO}_4)_3 + 10\text{H}_2\text{O} \dots$	97	$\text{Al}_2(\text{SO}_4)_3 + 7\text{H}_2\text{O} \dots$	White.
$\text{Al}_2(\text{SO}_4)_3 + 7\text{H}_2\text{O} \dots$	109	$\text{Al}_2(\text{SO}_4)_3 + 4\text{H}_2\text{O} \dots$	White.
$\text{Al}_2(\text{SO}_4)_3 + 4\text{H}_2\text{O} \dots$	180	$\text{Al}_2(\text{SO}_4)_3 + \text{H}_2\text{O} \dots$	White.
$\text{Al}_2(\text{SO}_4)_3 + \text{H}_2\text{O} \dots$	316	$\text{Al}_2(\text{SO}_4)_3$	White.
$\text{CuSO}_4 + 5\text{H}_2\text{O} \dots$	27	$\text{CuSO}_4 + 3\text{H}_2\text{O} \dots$	Sky blue.
$\text{CuSO}_4 + 3\text{H}_2\text{O} \dots$	93	$\text{CuSO}_4 + \text{H}_2\text{O} \dots$	Pale blue.
$\text{CuSO}_4 + \text{H}_2\text{O} \dots$	155	$\text{CuSO}_4 \dots$	White.
$\text{MnSO}_4 + 5\text{H}_2\text{O} \dots$	25	$\text{MnSO}_4 + 2\text{H}_2\text{O} \dots$	Pale peach blossom.
$\text{MnSO}_4 + 2\text{H}_2\text{O} \dots$	60	$\text{MnSO}_4 + \text{H}_2\text{O} \dots$	Paler than preceding.
$\text{MnSO}_4 + \text{H}_2\text{O} \dots$	152	$\text{MnSO}_4 \dots$	Paler than preceding.
$\text{ZnSO}_4 + 7\text{H}_2\text{O} \dots$	25	$\text{ZnSO}_4 + 6\text{H}_2\text{O} \dots$	White.
$\text{ZnSO}_4 + 6\text{H}_2\text{O} \dots$	28	$\text{ZnSO}_4 + 2\text{H}_2\text{O} \dots$	White, granular.
$\text{ZnSO}_4 + 2\text{H}_2\text{O} \dots$	115	$\text{ZnSO}_4 + \text{H}_2\text{O} \dots$	White.
$\text{ZnSO}_4 + \text{H}_2\text{O} \dots$	225	$\text{ZnSO}_4 \dots$	White.
$\text{NiSO}_4 + 7\text{H}_2\text{O} \dots$	40	$\text{NiSO}_4 + 4\text{H}_2\text{O} \dots$	Green.
$\text{NiSO}_4 + 4\text{H}_2\text{O} \dots$	106	$\text{NiSO}_4 + \text{H}_2\text{O} \dots$	Yellow.
$\text{NiSO}_4 + \text{H}_2\text{O} \dots$	279	$\text{NiSO}_4 \dots$	Orange colored.
$\text{CoSO}_4 + 7\text{H}_2\text{O} \dots$	19	$\text{CoSO}_4 + 4\text{H}_2\text{O} \dots$	Rose.
$\text{CoSO}_4 + 4\text{H}_2\text{O} \dots$	58	$\text{CoSO}_4 + \text{H}_2\text{O} \dots$	Lilac.
$\text{CoSO}_4 + \text{H}_2\text{O} \dots$	276	$\text{CoSO}_4 \dots$	Lilac.
$\text{CdSO}_4 + \frac{8}{3}\text{H}_2\text{O} \dots$	30	$\text{CdSO}_4 + 2\text{H}_2\text{O} \dots$	White.
$\text{CdSO}_4 + 2\text{H}_2\text{O} \dots$	41	$\text{CdSO}_4 + \text{H}_2\text{O} \dots$	White.
$\text{CdSO}_4 + \text{H}_2\text{O} \dots$	170	$\text{CdSO}_4 \dots$	White.
$\text{MgSO}_4 + 7\text{H}_2\text{O} \dots$	19	$\text{MgSO}_4 + 6\text{H}_2\text{O} \dots$	White.
$\text{MgSO}_4 + 6\text{H}_2\text{O} \dots$	38	$\text{MgSO}_4 + 2\text{H}_2\text{O} \dots$	White.
$\text{MgSO}_4 + 2\text{H}_2\text{O} \dots$	112	$\text{MgSO}_4 + \text{H}_2\text{O} \dots$	White.
$\text{MgSO}_4 + \text{H}_2\text{O} \dots$	203	$\text{MgSO}_4 \dots$	White.
$\text{CaSO}_4 + 2\text{H}_2\text{O} \dots$	38	$\text{CaSO}_4 + \text{H}_2\text{O} \dots$	White.
$2\text{CaSO}_4 + 2\text{H}_2\text{O} \dots$	80	$2\text{CaSO}_4 + \text{H}_2\text{O} \dots$	White.
$2\text{CaSO}_4 + \text{H}_2\text{O} \dots$	149	$2\text{CaSO}_4 \dots$	White.

In roasting calcareous<sup>5</sup> ores containing metallic sulphides the lime is converted almost quantitatively to  $\text{CaSO}_4$ .<sup>1</sup>  $\text{CaSO}_4$  is reduced by CO, the reaction beginning about  $680^\circ\text{C}$ . and being complete at  $900^\circ\text{C}$ .



$\text{CaSO}_4$  is also reduced by C, the reaction beginning at  $700^\circ\text{C}$ . and being complete at about  $1000^\circ\text{C}$ . At over  $800^\circ\text{C}$ . the gaseous end product is CO.

$\text{CaS}$ , if roasted<sup>6</sup> in air gives a product about 76 per cent.  $\text{CaSO}_4$  and 24 per cent.  $\text{CaO}$ . There is a reaction  $3\text{CaSO}_4 + \text{CaS} = 4\text{CaO} + 2\text{SO}_2$  that accounts for this loss of sulphur. This reaction will not take place in a reducing atmosphere.

Pure  $\text{CaSO}_4$  in the presence of oxygen loses its combined water at  $900^\circ\text{C}$ . and begins to decompose at from  $1250^\circ\text{C}$ . to  $1300^\circ\text{C}$ . In the presence of  $\text{SiO}_2$  it begins to give off  $\text{SO}_2$  at  $1000^\circ\text{C}$ . and the reaction is complete at  $1250^\circ$  to  $1300^\circ\text{C}$ . The action is shown in the equation



At a low temperature,  $\text{CaS}$  and  $\text{FeSO}_4$  interact.

Calcium sulphate roasted above  $870^\circ\text{C}$ . is practically insoluble; below that it is plaster of paris.

### Reduction of Chlorides by Hydrogen

Chloride	Product	Reduction begins
$\text{AgCl}$	Ag	About $526^\circ\text{C}$ .
$\text{Cu}_2\text{Cl}_2$	Cu	About $230^\circ\text{C}$ .
$\text{PbCl}_2$	Pb	About $500^\circ\text{C}$ .
$\text{FeCl}_2$	Fe.	Below $700^\circ\text{C}$ .
$\text{ZnCl}_2$	Zn	$602^\circ\text{C}$ .

### Reduction of Zn O begins

With $\text{CO}$ . . . . .	at about $627^\circ\text{C}$ .
With $\text{H}_2$ . . . . .	at about $527^\circ\text{C}$ .
With $\text{CH}_4$ . . . . .	at about $520^\circ\text{C}$ .

The reduction of  $\text{ZnO}$ , as carried on commercially, is a "gaseous" reduction, and for its continuance depends on the reaction  $\text{CO}_2 + \text{C} = 2\text{CO}$ ; the reaction  $\text{ZnO} + \text{CO} = \text{Zn} + \text{CO}_2$  furnishing further  $\text{CO}_2$  and the carbonaceous material of the charge furnishing C for the "producer reaction." It seems<sup>7</sup> proved that absolutely pure C and pure  $\text{ZnO}$  could not react (BODENSTEIN, *Trans. A.E.C.S.*, May meeting, 1927). The high temperatures of zinc distillation have not been necessary for the reaction  $\text{ZnO} + \text{CO} = \text{Zn} + \text{CO}_2$  but for the reaction  $\text{CO}_2 + \text{C} = 2\text{CO}$ .

<sup>1</sup> HOFMAN and MOSTOWITSCH, *Trans. A. I. M. E.*, 1910, **41**, 763.

**CO - CO<sub>2</sub> - C EQUILIBRIUM**  
(Excess Carbon Present Acting on CO<sub>2</sub> to Produce CO)

Temperature, deg. C.	Per cent. CO at equilibrium	Temperature, deg. C.	Per cent. CO at equilibrium
1,200	99.94	800	89.70
1,100	99.85	750	77.30
1,050	99.61	700	59.90
1,000	99.35	650	40.60
950	98.59	600	23.95
900	97.78	550	11.90
850	93.90	500	5.40
		450	2.15

The above table is a calculated one, using the results obtained by RHEAD and WHEELER, BOUDOUARD, and LEWIS and RANDALL. It does not agree, therefore with the published results of any of these authors. The excess carbon must not be graphitic, at least not below 850°C.

### Reduction of Oxides

CO begins to reduce CuO at 130°C.

H begins to reduce SnO<sub>2</sub> at 250°C.

H begins to reduce WO<sub>3</sub> at 620°C. approx.

H begins to reduce MoO<sub>3</sub> at 300°C. approx.

### Reduction of Metallic Oxides

The reducibility of an oxide by a reducing gas depends on the chemical nature of the oxide being reduced; whether the reduction is autocatalytic; the temperature and method of preparation of the oxide; whether the material is being reduced in mass, or is supported in thin layers on a suitable conducting medium; whether or not there are present materials which increase the activity of the metallic catalyst resulting from the reaction. The "chemical nature" noted above, is the position in the electrochemical series (p. 371), from which the ease of reduction can be approximated. As an example of autocatalytic reduction, when CuO is reduced by CO or H<sub>2</sub>, the reduction spreads from nuclei. These may take hours to form, so that the rate of reduction may be too small to measure for several hours. Once started, the reduction rate rises rapidly, passes a maximum and decreases as the oxide becomes exhausted. The addition of copper causes the reduction to start immediately. Nickel reduction is autocatalytic but the addition of metallic nickel does not accelerate the reaction. The reduction of vanadium pentoxide to tetroxide is also autocatalytic. Ferric oxide reduction is non-autocatalytic. As to the method and temperature of preparation, copper oxide formed by ignition of copper reduced at 175, 193, and 198°C.,

oxide formed by dehydrating  $\text{Cu}(\text{OH})_2$  at various temperatures reduced at 87, 135, and  $140^\circ\text{C}$ . The higher the temperature of preparation of nickel oxide, the higher the temperature of reduction and the less the autocatalytic character of the reduction. Nickel oxide supported on kieselguhr required a much higher temperature of reduction than when not supported. Certain substances act as retarders.  $\text{NiO}$  containing 10 per cent. thoria requires a considerably higher temperature of reduction than thoria-free oxide.  $\text{Fe}_3\text{O}_4$  containing 1 per cent.  $\text{K}_2\text{O}$  and 3 per cent.  $\text{Al}_2\text{O}_3$  reduces only about half as rapidly as  $\text{Fe}_3\text{O}_4$  not containing these substances (P. H. EMMETT, *Trans. A.E.C.S.*, 1927).

### Reduction Temperatures of Metallic Oxides

Various metallic oxides were submitted to the action of hydrogen, carbon monoxide, ammonia and methane, at various temperatures for a period of 6 hours, and the investigators report in the *Journ. Soc. Chem. Ind.*, July 30, 1910, the lowest temperatures at which the oxides begin to lose oxygen. The accompanying tabulation shows the results obtained.

#### TEMPERATURES AT WHICH OXIDES OF THE METALS GIVE UP OXYGEN

Oxide	Carbon monoxide, deg. C.	Hydrogen, deg. C.	Ammonia, deg. C.	Methane, deg. C.
$\text{Au}_2\text{O}_3$	0 and below	0 and below	.....	.....
$\text{Ag}_2\text{O}$ .....	0	0	.....	.....
$\text{Hg}_2\text{O}$ .....	0	80	67	220
$\text{HgO}$ (yellow)	0 and below	50	.....	.....
$\text{HgO}$ (red)....	90	115	157	200-210
$\text{Pb}_2\text{O}_3$ .....	.....	.....	202	202
$\text{PbO}_2$ .....	110	150	198	45
$\text{Pb}_2\text{O}_4$ .....	150	170	Above 300	158
$\text{PbO}$ .....	160	190	299	210
$\text{CuO}$ .....	75	125	225	280
$\text{Cu}_2\text{O}$ .....	.....	.....	208	230
$\text{CoO}$ .....	140	.....	.....	.....
$\text{ZnO}$ .....	170	.....	233	152-159
$\text{As}_2\text{O}_3$ .....	60	.....	.....	.....

### Reduction Temperatures of Some Refractory Oxides<sup>1</sup>

Oxide and carbon	Reduction temperature	Remarks
$\text{BeO}$	$2400^\circ$	Forms carbide.
$\text{MgO}$	.....	Oxide dissociates before reduction.
$\text{CaO}$	$1540^\circ$	Carbide dissociates above $800^\circ$ .
$\text{Al}_2\text{O}_3$	$1800^\circ$	Forms carbide.
$\text{B}_2\text{O}_3$	$2400^\circ$	Carbide sublimes.
$\text{MnO}$	$1100^\circ$	Carbide dissociates at $1550^\circ$ .
$\text{UO}_2$	$1600^\circ$	Forms carbide.

<sup>1</sup> Zeit. angew. Chemie., 1915, Vol 28, p. 118.

## Reduction by Hydrogen

A paper on "The Reduction of Metallic Oxides with Hydrogen at High Pressures," by E. Newberry and J. N. Pring, was read at a meeting of the Royal Society January, 1916. Metallic oxides have been heated to temperatures of 2500°C. in dry hydrogen at pressures up to 150 atmospheres, water vapour being removed by metallic sodium. The following oxides were reduced to metals:  $\text{Cr}_2\text{O}_3$  to Cr and  $\text{MnO}_2$  to Mn. The following oxides were reduced to lower oxides:  $\text{V}_2\text{O}_5$  to VO,  $\text{Nb}_2\text{O}_5$  to NbO,  $\text{U}_3\text{O}_8$  to  $\text{UO}_2$ ,  $\text{TiO}_2$  to TiO, and  $\text{CeO}_2$  to  $\text{Ce}_2\text{O}_3$ . The following oxides were unchanged:  $\text{Al}_2\text{O}_3$ , MgO,  $\text{ZrO}_2$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{ThO}_2$ . The metals obtained, chromium and manganese, are probably the purest samples of these metals that have been prepared up to the present. This supposition is supported by the sharp nature of their melting points, a feature which has not been observed with samples prepared by other methods.

Decomposition of Carbonates<sup>1</sup>

$\text{ZnCO}_3$	= ZnO + $\text{CO}_2$	300°C.
$\text{MgCO}_3$	= MgO + $\text{CO}_2$	650°C.
$\text{FeCO}_3$	= No simple product	800°C.
$\text{CaCO}_3$	= CaO + $\text{CO}_2$	812°C.
$\text{SrCO}_3$	= SrO + $\text{CO}_2$	begins 1141°C.
$\text{BaCO}_3$	= BaO + $\text{CO}_2$	begins 1361°C.
$\text{MgCO}_3$	= MgO + $\text{CO}_2$	546°C.

Decomposition of Sulphides<sup>1</sup>

Pyrite — $\text{FeS}_2$	= FeS + S	565°C.
Chalcopyrite		720°C.

## Oxidation of Metallic Oxides at High Temperatures and Pressures

J. MILBAUER has experimented on the reactions of metallic oxides at high temperatures and pressures (*Journ. Soc. Chem. Ind.*, May 31, 1916). When heated in oxygen for an hour at 480°C., and 12 atmospheric pressure, most of the normal metallic oxides remained unchanged. The following exceptions were noted: Potassium and barium oxides were converted into peroxides, lead oxide into red lead, antimony oxide into the tetroxide, and manganese oxide into sesquioxide; the lower oxides of nickel and cobalt yielded traces of nickelic and cobaltic oxides. Silver was converted into black crusts of, apparently, a peroxide, since on treatment with hydrochloric acid they yielded chlorine. Platinum remained unchanged. Experiments under similar conditions with metallic oxides intimately mixed with

<sup>1</sup> See pp. 695 and 696 for additional data.

chromium sesquioxide, showed in many cases a more or less complete conversion into metallic chromate with absorption of oxygen. Thus, for example, the products obtained from chromium oxide and the following oxides (or carbonates) contained the annexed percentages of chromate respectively: Silver oxide, 100 per cent. of chromate; magnesium oxide, 82.7 per cent.; calcium oxide, 56.9 per cent.; zinc oxide, 72 per cent.; and lead carbonate, 100 per cent. The reaction is therefore available for the preparation of certain chromates, notably that of magnesium, which in many cases can be substituted for alkali chromates.

### Molecular Heat of Dilution<sup>1</sup>

The heat set free or absorbed on diluting a gram molecule of liquid with water is the molecular heat of dilution, thus on diluting HCl to (HCl, 300 H<sub>2</sub>O) 17,300 cal. per 36.5 grams of HCl are set free; diluting 2NaCl, nH<sub>2</sub>O (n = 20) to (2NaCl, 100 H<sub>2</sub>O) absorbs 1060 cal. per 2 × 58.65 grams of NaCl.

HCl n = 0 H <sub>2</sub> O	HNO <sub>3</sub> n = 0 H <sub>2</sub> O	H <sub>2</sub> SO <sub>4</sub> n = 0 H <sub>2</sub> O	NaOH n = 3 H <sub>2</sub> O	NH <sub>3</sub> <sup>a</sup> n
1 5,370 2 11,360 5 14,960 50 17,100 300 17,300	1 3,280 5 6,600 10 7,320 20 7,400 320 7,490	1 6,380 5 13,100 49 16,700 199 17,100 1,600 17,900	5 2,130 7 2,900 9 3,100 25 3,260 200 2,940	1 1,260 3 385 5.8 210 9.5 20 110 .....
2NaCl n = 20 H <sub>2</sub> O	2NaNO <sub>3</sub> n = 12 H <sub>2</sub> O	Na <sub>2</sub> SO <sub>4</sub> n = 50 H <sub>2</sub> O	ZnCl <sub>2</sub> n = 5 H <sub>2</sub> O	Zn(NO <sub>3</sub> ) <sub>2</sub> n = 10
100 -1,060 200 -1,310 400 -1,410 .....	50 -2,260 100 -3,290 200 -3,860 400 -4,190 .....	100 - 665 200 -1,130 400 -1,380 800 -1,480 .....	10 1,850 20 3,150 50 5,320 100 6,810 400 8,020	15 910 20 1,150 50 1,200 100 1,100 200 1,070

### STANDARDS FOR WORK WITH THE BOMB CALORIMETER<sup>2</sup>

	Berthelot	Atwater	Fischer & Wrede	U. S. Bureau of Standards
Naphthalene. <sup>4</sup>	9692	9628	9640	9610
Benzoic acid.....	6322	6322	6333	6320
Cane sugar (sucrose)	3961	3957	3957	

<sup>1</sup> From KANE and LABY, Physical and Chemical Constants."

<sup>2</sup> Heat developed on diluting NH<sub>3</sub>·nH<sub>2</sub>O to NH<sub>3</sub>·200H<sub>2</sub>O (BERTHELOT).

<sup>3</sup> From SOMERMEIER'S "Coal."



## Thermoelectric Constants

The electromotive forces<sup>1</sup> given by various thermo-couples in general use, and at a temperature of 500°C., with the cold junction temperature 0°C., are as follows:

Name of thermo-couple	Approximate electromotive force in millivolts at 500°C.
Platinum-platinum 10 per cent rhodium.	4.4
Platinum-platinum 10 per cent iridium.	7.4
Nickel-nickel 10 per cent. chromium (The Hoskin's couple).	10.0
Iron-nickel	12.0
Iron-constantan.	26.7
Silver-constantan.	27.6
Copper-constantan	27.8
Chromel-alumel	20.7

The relation between temperature and the electromotive force produced by a thermo-couple when the cold junction is maintained at 0°C. is usually given in an equation of the form

$$\log e = A \log t + B,$$

where

$e$  = e.m.f. of the thermo-couple in millivolts,

$t$  = the temperature of the thermo-couple in degrees Centigrade,

and  $A$  and  $B$  are constants depending on the wire employed.

For chief thermo-couples in general use at the present time this equation is as follows:

Platinum-platinum rhodium approximately	$\log e = 1.19 \log t + 0.52$
Platinum-platinum iridium approximately	$\log e = 1.10 \log t + 0.89$
Silver-constantan approximately.	$\log e = 1.14 \log t + 1.34$

(See also p. 202.)

## THERMOCHEMICAL CONSTANTS PER CHEMICAL EQUIVALENT WITH CORRESPONDING VOLTAGES

In the table of thermo-chemical constants per chemical equivalents (by J. W. Richards, *Journ. Franklin Inst.*, 1906) the column headed "per chemical equivalents" gives the additional energy in case of the plus figures, or the smaller amount, in case of the negative, required to set free a chemical equivalent (molecular weight divided by valence) of the given substance as compared with the energy required to decompose the corresponding hydrogen compound.

In the formation of  $\text{CuCl}_2$  the data in the table are - 7900 Cu, + 39,400  $\text{Cl}_2$  = 31,500 gram-cal. required for the decomposition of one chemical equivalent of  $\text{CuCl}_2$ , the corresponding drop in voltage is - 0.34 Cu, + 1.71  $\text{Cl}_2$  = 1.37 volts for the decomposition voltage of  $\text{CuCl}_2$ . The order in which the elements are placed gives also the order in which they will be deposited one after another by decreasing voltages.

<sup>1</sup> *Engineering*, Aug 1, 1913.

Basic elements			Element	Acid elements		Salt
Element	Per chemical equivalents, gram-cals.	Corresponding voltage		Per chem. equiv., gram-cal	Corresponding voltage	
Li'	+62,900	+2.73	F <sub>2</sub> ' (gas)...	+52,900	+2.30	Fluoride.
Rb'	+62,000	+2.69	Cl <sub>2</sub> ' (gas)...	+39,400	+1.71	Chloride.
K'	+61,900	+2.69	Br <sub>2</sub> ' (gas)...	+32,300	+1.40	Bromide.
Ba''	+59,950	+2.60	Br' (liquid)...	+28,600	+1.20	Bromide.
Sr''	+58,700	+2.55	Br' (solid)...	+27,300	+1.18	Bromide.
Na'	+57,200	+2.48	I <sub>2</sub> ' (gas)...	+20,000	+0.87	Iodide.
Ca''	+54,900	+2.36	I' (liquid)...	+14,600	+0.63	Iodide.
Mg''	+54,300	+2.36	I' (solid)...	+13,200	+0.57	Iodide.
Al''	+40,100	+1.74	S'' (solid)...	-5,100	-0.22	Sulphide.
NH <sub>4</sub> '	+33,400	+1.45	Se'' (met.)...	-17,900	-0.78	Selenide.
Mn''	+24,900	+1.08				
Zn''	+17,200	+0.75				
Fe''	+19,900	+0.47				
Cd''	+9,000	+0.39				
Co''	+8,200	+0.36				
Ni''	+7,700	+0.33				
Fe'''	+3,230	+0.14				
Sn''	+1,900	+0.08				
Pb''	+400	+0.02				
H'	0	0				
Tl'	-900	-0.04				
Cu''	-7,900	-0.34				
Hg''	-14,250	-0.62				
Pt'''	-19,450	-0.84				
Ag'''	-25,200	-1.10				
Au'''	-30,300	-1.32				

### Calculation of Electromotive Force (THOMSON'S RULE)

One coulomb liberates 0.000010392 grams of H. In order to set free 1 gram of H, or 1 gram equivalent of any other element, an expenditure of  $1 \div 0.000010392 = 96,500$  coulombs is required. This is known as a Faraday and is usually denoted by the letter  $F$ .

If  $Q$  is the heat energy of formation of one molecular weight,  $n$  the valence of the compound, then

$$nEF = Q \times 4.19$$

$$F = 96,500$$

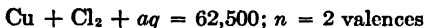
$$E = \frac{Q}{23,030n} \text{ (THOMSON'S rule).}$$

The rule is not quite correct. The true relation between heat and electrical energy is given by the GIBBS-HELMHOLTZ equation

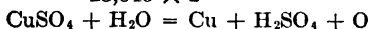
$$nEF = Q + T \frac{dE}{dT}$$

in which  $T$  = absolute temperature, and  $\frac{dE}{dT}$  is the temperature coefficient of the e.m.f. As this coefficient is usually not large, THOMSON'S rule is sometimes used to give an approximate value.

Example:



$$E = \frac{62,500}{23,040 \times 2} = 1.36 \text{ volts}$$



$$197,500 + 69,000 - 210,000 = 56,300$$

$$E = \frac{56,300}{2 \times 23,040} = 1.22 \text{ volts}$$

### Electroplating Baths<sup>1</sup>

**Brass Bath (ROSELEUR'S).**—Per liter of water:

Sodium carbonate, dry ( $\text{Na}_2\text{CO}_3$ )	10 g.
Cupric acetate, pulverized	14 g.
Sodium bisulphite ( $\text{HNaSO}_3$ )	14 g.
Zinc chloride, fused ( $\text{ZnCl}_2$ )	14 g.
Potassium cyanide (100 per cent. KCN)	40 g.
Ammonium chloride ( $\text{NH}_4\text{Cl}$ )	2 g.

Current density, 0.3 amp. per sq. dm.; e.m.f., 2.7 volts; sp. gr., 1.0545; deposit per hour, 0.0041 mm.

Dissolve the sodium salts in 400 cc. warm water, stir the copper and zinc salts with 400 cc. of warm water, and stir slowly into the first solution. Dissolve the cyanide in the remainder of the water and stir into the other portion of the bath, where the precipitate should dissolve. Add the ammonium chloride and boil for an hour, replacing the water evaporated.

**Cadmium.**—A cyanide bath is recommended. A few hundredths of a per cent. of nickel, cobalt, or copper is said to improve the deposit.

**Chromium Plating.**—In chromium plating, it is most important to have the current on, so that immersing the work to be plated closes the circuit. The bath recommended by the Bureau of Standards is 250g. per liter of chromic anhydride,  $\text{CrO}_3$ ; 3g. chromic sulphate,  $\text{Cr}_2(\text{SO}_4)_3$ ; and 7g. chromium carbonate,  $\text{Cr}_2\text{O}(\text{CO}_3)_2$ . The current density recommended is 22 amp. per sq. dm., run at temperatures from 40 to 50°C. Chromium plating can be stripped from nickel or steel by making it the anode in the same bath as used for plating. See "Nickeling on Aluminum" p. 367, for some data on chrome plating on aluminum.

**Copper Bath—Acid.**—Per liter of water:

Copper sulphate ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ )	200 g.
Sulphuric acid (conc. $\text{H}_2\text{SO}_4$ )	30 g.

Current density, 1 to 3 amp. per sq. dm.; sp. gr. 1.1417.

<sup>1</sup> "A Laboratory Course in Electrochemistry," WATTS.

**Copper Bath—Alkaline.**—Per liter of water:

Sodium sulphite ( $\text{Na}_2\text{SO}_3$ ).....	20 g.
Sodium carbonate ( $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ ).....	20 g.
Sodium bisulphite ( $\text{HNaSO}_3$ ).....	20 g.
Cupric acetate ( $\text{Cu} \cdot 2\text{C}_2\text{H}_3\text{O}_2 \cdot \text{H}_2\text{O}$ ).....	20 g.
Potassium cyanide (100 per cent. KCN).....	20 g.

Current density, 0.3 amp.; e.m.f., 2.9 volts; sp. gr., 1.0507; deposit in 1 hour, 0.0056 mm.; temp.,  $20^\circ\text{C}$ .; make-up as under brass bath.

Copper-nickel alloys may be deposited from a double solution of copper and nickel cyanides, 50 to 150 grams per liter. Satisfactory anode corrosion is obtained by the addition of 5 to 40 grams per liter of KCl. The bath must be worked at a low temperature, preferably below  $18^\circ\text{C}$ . Current as high as 25 amp. per sq. dm. can be used.

**Cobalt Bath I.**—Cobalt-ammonium sulphate,  $\text{CoSO}_4 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$ , 200 grams per liter of water (or 145 grams of the anhydrous salt). Sp. gr., 1.053 at  $15^\circ\text{C}$ .

**Cobalt Bath II.**—Cobalt sulphate,  $\text{CoSO}_4$ , 312 grams, sodium chloride, NaCl, 19.6 grams, boric acid, nearly to saturation, water, 1000 cc. Sp. gr., 1.25 at  $15^\circ\text{C}$ .

Use cobalt anodes, and current even up to 160 amp. per square foot where possible (H. T. KALMUS *et al.*, *Electrical Review*, May 8, 1915).

**Gold Bath.**—Per liter of water:

Sodium carbonate, dry ( $\text{Na}_2\text{CO}_3$ ).....	10 g.
Gold-ammonium chloride $(\text{NH}_4)_2\text{AuCl}_6$ .....	2 g.
Potassium cyanide.....	7 g.

Current density, 0.1 amp. per sq. dm.; e.m.f., 2.8 volts; sp. gr., 1.0175; deposit per hour, 0.00184 mm.; temperature,  $20^\circ\text{C}$ .; anode area one-third cathode.

Duriron makes a very serviceable anode in gold cyanide solutions (M. de K. THOMPSON). The alloy withstands corrosion well and makes a better anode than lead in the electrolytic extraction of gold.

**Iron Bath.**—Per liter of water:

Ferrous sulphate ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ).....	150 g.
Ferrous chloride ( $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ ).....	75 g.
Ammonium sulphate $(\text{NH}_4)_2\text{SO}_4$ .....	100 g.

Current density, 1.0 amp. This bath can be used for refining iron. At  $20^\circ\text{C}$ . the deposit is hard and brittle, but electrolysis at  $80^\circ$  to  $90^\circ$  yields a soft metal. See also p. 767.

**Lead Bath.**—Per liter of water:

Lead (as $\text{PbSiF}_6$ ).....	50 to 80 g.
Hydrofluosilicic acid ( $\text{H}_2\text{SiF}_6$ ).....	100 to 150 g.
Gelatin.....	0.5 g.

Current density, 1.2 to 1.6 amp. per sq. dm. This bath is used for refining. For plating reduce the free acid to 2 or 3 per cent.

**Nickeling on Aluminum.**—For both nickel and chrome plating on aluminum a roughened aluminum surface appears preferable to a smooth one. In general, any bath that will nickel on zinc appears satisfactory for aluminum. A bath with a pH of 6 gives best results, and nickeling before chrome plating appears advisable.

**Nickel Plating.**—C. T. THOMAS and W. BLUM of the Bureau of Standards state that nickel plating thinner than 0.001 in. (0.025 mm.) is useless. Nickel deposits with a high iron content turn yellow and permit excessive corrosion of the underlying steel. Deposits containing a substantial copper layer, either prior to the nickel coating, or between two layers of nickel, furnish a far better protection against atmospheric corrosion than do deposits of pure nickel of the same thickness. (*Trans. A.E.C.S.*, 1927.)

**Nickeling on Iron or Steel.**—Per liter of water:

Nickel-ammonium sulphate..... 75 g.

Current density, 0.3 amp.; e.m.f., 3.5 volts; sp. gr., 1.0479; deposit per hour, 0.0034 mm.; cast anodes should be half the area of cathode. A little boric acid in the bath gives a brighter deposit.

**Nickeling on Brass or Copper.**—Per liter of water:

Nickel sulphate ( $\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$ )..... 50 g.

Ammonium chloride ( $\text{NH}_4\text{Cl}$ )..... 25 g.

Current density, 0.5 amp. per sq. dm.; e.m.f., 2.3 volts; sp. gr. 1.0357; deposit in 1 hour, 0.0059 mm.; cast anodes should be one-half area of cathode.

**Nickeling on Zinc.**—Per liter of water:

Nickel sulphate..... 40 g.

Sodium citrate..... 35 g.

Current density, 0.27 amp. per sq. dm.; e.m.f., 3.6 volts; sp. gr., 1.0394; deposit per hour, 0.00301 mm; rolled anodes should have two and one-half times area of cathodes.

**Nickel Solution—Thick Deposits.**—Per liter of water:

Nickel sulphate,  $\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$ . . . . . 50 g.

Ammonium tartrate, neutral. . . . . 36 g.

Tannin..... 0.25 g.

Current density, 0.3 amp. per sq. dm.

**Black Nickel.**—Per liter of water:

Nickel-ammonium sulphate... . . . . 60 g.

Ammonium sulphocyanide..... 15 g.

Zinc sulphate, cryst..... 7 g.

Use nickel anodes three to four times the surface of the cathodes. Current density, 0.05 amp. per sq. dm. Deposit takes best on white nickel. Solution must be kept neutral by nickel carbonate.

**Platinum Bath**—(ROSELEUR's).—Per liter of water:

	Thin deposits	Thick deposits
Ammonium phosphate.....	20.0 g.	100.0 g.
Sodium phosphate.....	100.0 g.	100.0 g.
Platinum as $\text{PtCl}_4$ .....	2.3 g.	10.0 g.

Current density, 1 to 2 amp. per sq. dm.; e.m.f., 3 to 4 volts.

Dissolve the platinum chloride in 100 cc. of water. Dissolve the ammonium phosphate in 200 cc. of water and stir into the platinum solution, when the precipitate previously formed will dissolve. Boil until odor of ammonia has disappeared and add water to make up for evaporation. Bath should have acid reaction and should be used hot. Potential difference, 6–8 volts.

**Silver Bath—Heavy Plating.**—Per liter of water:

Silver as silver cyanide.....	25 g.
Potassium cyanide .....	27 g.

Current density, 0.3 amp.; e.m.f., 1.3 volts; sp. gr., 1.0338; deposit per hour, 0.0114 mm.; area of anodes equals area of cathode.

**Silver Bath—Ordinary Plating.**

Silver as silver cyanide.....	10 g.
Potassium cyanide .....	20 g.

Current density, 0.3 amp. per sq. dm.; e.m.f., 1.5 volts; sp. gr., 1.0175; deposit per hour, 0.0115 mm.

**Thallium Plating.**—Smooth, coherent deposits of thallium can be obtained with 80 to 160 grams of thallium chlorate per liter acidifying with perchloric acid. Peptone is used as an anodic depolarizer and cresylic acid as an addition agent. Current density 0.5 – 1.8 amp. per sq. dm.

**Tin Bath** (ROSELEUR's).—Per liter of water:

Sodium pyrophosphate ( $\text{Na}_4\text{P}_2\text{O}_7$ ) ..	40 g.
Tin chloride, fused ( $\text{SnCl}_2$ ) ..	16 g.
Tin chloride, cryst. ( $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ ) ..	4 g.

Current density, 0.3 amp. per sq. dm.; e.m.f., 2 volts; sp. gr., 1.0357; deposit per hour, 0.0059 mm.; anode area equal to cathode, solution gives deposit on copper, brass, bronze or zinc; but iron or steel must be coppered first or given a preliminary coat of tin by an immersion bath. The tin anodes do not corrode evenly and tin salts must be added to maintain sufficient amount of tin in solution.

**Tin Baths.**—Per liter of water:

		a	b	c
Caustic soda.....	( $\text{NaOH}$ )	90 g.	120 g.	125 g.
Tin chloride, cryst.....	( $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ )	30 g.	30 g.	50 g.
Sodium hyposulphite....	( $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ )	15 g.	60 g.	75 g.
Sodium chloride.....	( $\text{NaCl}$ )	15 g.	.....	.....

**Tin Bath, by Immersion.**—Per liter of water:

Ammonium alum ( $\text{NH}_4\text{Al}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ )..... 25 g.  
 Tin chloride, fused ( $\text{SnCl}_2$ )..... 2 g.

A bright coating is produced on clean iron by 30 to 60 seconds immersion in the boiling solution.

**Zinc Bath.**—Per liter of water:

Zinc sulphate ( $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ )..... 100 g.  
 Ammonium chloride ( $\text{NH}_4\text{Cl}$ )..... 25 g.  
 Ammonium citrate..... 40 g.

Current density, 0.5 to 1.0 amp. per sq. dm.; e.m.f., 1.1 to 2.2; sp. gr., 1.0781; deposit per ampere-hour, 0.0173 mm.

**Zinc Bath.**—Per liter of water:

Zinc chloride..... 60 g.  
 Ammonium chloride..... 30 g.  
 Hydrochloric acid.... 4 g.  
 Glycerine..... 4 g.

Use anodes of zinc and of antimonial lead in equal numbers.

### Electrolytic Oxidation and Reduction

Overvoltage of Hydrogen and Oxygen.

(Quoted from WATTS "A Laboratory Course in Electrochemistry.")

"Electrolysis lends itself well to oxidation and reduction processes, since it is possible to vary not only the speed, but also the intensity of the action with great nicety. Factors affecting the intensity of the reducing action are the material of the electrode,

### OVERVOLTAGE OF HYDROGEN

Cathode	By Caspari <sup>1</sup> $\text{N}_2\text{H}_4\text{SO}_4$	By Foerster <sup>2</sup> and Pignet <sup>3</sup> $\text{N}_2\text{H}_4\text{SO}_4$		$2\text{N}_2\text{H}_4\text{SO}_4$ 0.125 amp. per sq. cm.	By Tafel <sup>4</sup> 0.1 amp. sq. cm.	Discharge potentials, $\text{N}_2\text{H}_4\text{SO}_4$	
		Least potential	Current 0.04 amp. per sq. cm.			From Caspari	From Foerster
Mercury...	0.78	0.43	1.25	1.32	1.30	+ .5476	+ .1976
Zinc.....	0.70	.....	.....	.....	.....	+ .4676	.....
Lead.....	0.64	0.35	1.26	1.35	1.30	+ .4076	+ .1176
Tin.....	0.53	0.43	1.08	1.16	1.15	+ .2976	+ .1676
Cadmium...	0.48	0.48	1.18	1.23	1.22	+ .2476	+ .1976
Palladium...	0.46	.....	.....	.....	.....	+ .2276	.....
Copper.....	0.23	0.10	0.67	0.79	0.79	-.0024	-.1324
Nickel....	0.21	0.10	0.64	0.74	0.74	-.0224	-.1324
Silver....	0.15	.....	.....	.....	0.93(?)	-.0824	.....
Platinum...	0.09	0.07	.....	.....	.....	-.1424	-.1624
Gold.....	0.02	0.055	0.86	0.96	0.95	-.2174	-.1874
Platinized-platinum..	0.0	0.005	0.05	0.07	0.07	-.2324	-.2274

NOTE.—"N" in the above table stands for normal.

<sup>1</sup> *Zeit. phys. Chem.*, 1899, p. 89.

<sup>2</sup> *Zeit. f. Elektrochem.*, 1904, p. 715.

<sup>3</sup> *Zeit. f. Chem.*, 1904, p. 712.

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the nature of its surface, and the current density. In comparing the effects of different cathodes, an attempt is frequently made to resolve the reducing action of the cathodes into the catalytic action of the electrode material, and the 'overvoltage' of the hydrogen. The variation in the potential required by electrodes of different metals for visible evolution of hydrogen is usually expressed as the 'overvoltage' of hydrogen on the particular metal, the least potential of platinized platinum being taken as zero. The discharge potentials referred to the calomel electrode (value,  $-0.56$  volt) have been calculated for the difference between the calomel electrode and the hydrogen electrode in normal sulphuric acid. The increase of overvoltage with time and its diminution with rise of temperature varies for different metals."

ANODE POTENTIALS AND OVERVOLTAGE OF OXYGEN

Anode	By Coehn. Least anode potential for evolution of $O_2$ vs. hyd. electrode in N KOH	Overvoltage Allmand, p. 131	Discharge potential vs. calomel electrode calculated by Watts	By Foerster. Least potential for evolution hyd vs. hyd. electrode 2N KOH	2N KOH after 2 hours, 15°C.	2N KOH 99°C.	2N $H_2SO_4$ = 99°C.
Nickel, sponge.	1 28	0.05	-0.9524	..	..	..	..
Nickel, smooth	1 35	0.12	-1.0224	1 35	2.00	1.77	..
Cobalt.....	1.36	0.13	-1.0324	..	..	..	..
Iron.....	1.47	0.24	-1.1424	1.47	2.02	1.80	..
Platinized-platinum	1 47	0 24	-1.1424	1 47	2.30	..	..
Copper.....	1.48	0 25	-1.1524	..	..	..	..
Lead.....	1.53	0.30	-1.2024	..	..	..	..
Silver.....	1 63	0 40	-1.3024	..	..	..	..
Cadmium...	1 65	0 42	-1.3224	..	..	..	..
Palladium...	1 65	0 42	-1.3224	1 65	2 45	..	..
Platinum...	1 67	0.44	-1.3424	1 67	2 92	2.50	2.17
Gold.....	1 75	0.52	-1.4224	..	..	..	..

On the matter of overvoltage and electrode potential, S. J. FRENCH and LOUIS KAHLENBERG presented a paper at the May meeting, 1925, of the American Electrochemical Society, in which the following points were emphasized:

All metals and gases form gas-metal electrodes, the potentials of which are specific for the particular gas and metal, and are related to the absorbing power of the metal for the gas and the affinity of the metal for each gas, in case of a mixture. The total combination potential is due both to the absorbed gas and a condensed film of gas on the surface of the metal. Oxygen tends to make the metal potentials less basic, while nitrogen and hydrogen have the opposite effect. Elements having a strong tendency to form acids behave differently with oxygen than do other elements. Elements having amphoteric properties, variable valences, and known to function as catalysts,



show greater changes with hydrogen and nitrogen than do the more simple and pronouncedly metallic elements. Carbon monoxide and methane alter the potentials of platinum and palladium materially. On other metals the effect of these gases is slight.

Coating electrodes and stirring the electrolyte has the same effect in preventing the condensation of the gas film on the surface of the electrode. This gas film is a definite phenomenon and because of its instability causes fluctuations in potential measurements. The so-called single potentials of the metals, determined as they are in air, are in reality the potentials of air-metal electrodes. The most constant electrodes are those which show the smallest difference between their oxygen and nitrogen potentials. The peculiar behavior of aluminum in the electromotive series is due to the formation of an oxygen-aluminum electrode. Amalgamation and alkali electrolytes permit of the formation of hydrogen at the surface of the aluminum electrode and thus give a more basic potential.

So far as theory goes, overvoltage is believed to be polarization due to electrically neutral monatomic gases.

In fused salts, the so-called "anode effect" seems to be due to local overheating at any point. This establishes a gas film at that point which diverts current to other points of the anode area, overloads them, and results in the practically instantaneous spread of the film over the whole anode surface. (C. S. TAYLOR, Aluminum Co. of America.)

### Electrochemical Order of the Elements<sup>1</sup>

In the following series each metal is electronegative to all that follow it. Two metals in contact in the presence of an electrolyte form a galvanic couple which causes the more electronegative to be decomposed by electrolysis.

Cs —, Rb, K, Na, Li, Ba, Sr, Ca, Mg, Al, Cr, Mn, Zn, Ga, Fe, Co, Ni, Tl, In, Pb, Cd, Sn, Bi, Cu, H, Hg, Ag, Sb, Te, Pd, Au, Ir, Rh, Pt, Os, Si, C, B, N, As, Se, P, S, I, Br, Cl, O, F.

Some authors put Cd just before Fe, Sn before Pb, and Sb and As before Cu. That the last two should precede copper ordinarily seems probable. The order changes with the specific electrolyte, and the position of selenium varies with the amount of illumination.

<sup>1</sup> GORE, "The Art of Electrolytic Separation of Metals."

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## POTENTIALS OF METALS IN THEIR NORMAL SALTS (NEUMANN)

	Sulphate	Chloride	Nitrate	Acetate
Magnesium.....	+1.239	+1.231	+1.060	+1.240
Aluminum.....	+1.040	+1.015	+0.775	.....
Manganese.....	+0.815	+0.824	+0.560	.....
Zinc.....	+0.524	+0.503	+0.473	+0.522
Cadmium.....	+0.162	+0.174	+0.122	.....
Iron.....	+0.093	+0.087	.....	.....
Cobalt.....	-0.019	-0.015	-0.078	-0.004
Nickel.....	-0.022	-0.020	-0.060	.....
Tin.....	.....	-0.085	.....	.....
Lead.....	.....	-0.095	-0.115	-0.079
Hydrogen.....	-0.238	-0.249	.....	-0.150
Bismuth.....	-0.490	-0.315	-0.500	.....
Antimony.....	.....	-0.376	.....	.....
Arsenic.....	.....	-0.550	.....	.....
Copper.....	-0.515	.....	-0.615	-0.580
Mercury.....	-0.980	.....	-1.028	.....
Silver.....	-0.974	.....	-1.055	-0.991
Palladium.....	.....	-1.066	.....	.....
Platinum.....	.....	-1.140	.....	.....
Gold.....	.....	-1.356	.....	.....

## DECOMPOSITION VOLTAGES (LE BLANC)

H <sub>2</sub> SO <sub>4</sub> ...	1.67	NaI.....	1.12	NiSO <sub>4</sub> ....	2.09		
HNO <sub>3</sub> ...	1.69	NaC <sub>2</sub> H <sub>3</sub> O <sub>2</sub>	2.10	NiCl <sub>2</sub> ....	1.84		
H <sub>3</sub> PO <sub>4</sub> ...	1.70	K <sub>2</sub> SO <sub>4</sub> ...	2.20	AgNO <sub>3</sub> ...	0.70		
HCl.....	1.31	KNO <sub>3</sub> ...	2.17	CdSO <sub>4</sub> ....	2.03	SnCl <sub>2</sub>	1.76
NaOH....	1.67	KCl.....	1.96	CoSO <sub>4</sub> ...	1.92	MnSO <sub>4</sub>	2.60
KOH.....	1.69	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	2.11	HgCl <sub>2</sub> ...	1.30	MnCl <sub>2</sub>	2.77
NH <sub>4</sub> OH..	1.74	CaCl <sub>2</sub> ...	1.89	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	1.64	CuCl <sub>2</sub>	1.36
Na <sub>2</sub> SO <sub>4</sub> ..	2.21	SrCl <sub>2</sub> ...	2.01	FeSO <sub>4</sub> ....	2.02		
NaNO <sub>3</sub> ..	2.15	BaCl <sub>2</sub> ...	1.95	AuCl <sub>3</sub> ...	0.39		
NaCl....	1.98	ZnSO <sub>4</sub> ...	2.35	FeCl <sub>2</sub> ....	2.16		
NaBr....	1.68	ZnBr....	1.80				

ELECTROMOTIVE FORCE OF METALS AND MINERALS IN KCN SOLUTIONS<sup>1</sup> $\left(\frac{M}{I} \text{ KCN } 6.5 \text{ Per Cent.}\right)$ 

	Volts		Volts
Aluminum.....	+0.99	Iron.....	-0.17
Zinc, amalgamated...	+0.93	Chalcopyrite.....	-0.20
Copper.....	+0.81	Pyrite.....	-0.28
Cadmium...	+0.61	Galena.....	-0.28
Tin.....	+0.45	Argentite.....	-0.28
Bornite.....	+0.43	Speiss (cobalt)....	-0.30
Copper, amalgamated.	+0.39(?)	Arsenopyrite.....	-0.40
Gold.....	+0.37	Platinum.....	-0.40
Silver.....	+0.33	Cuprite.....	-0.43
Copper glance.....	+0.29(?)	Electric-light carbon.	-0.46
Lead.....	+0.13	Blende.....	-0.48
Quicksilver.....	-0.09	Bournonite..	-0.50
Gold, amalgamated.	.....	Coke.....	-0.52
Antimony.....	+0.06	Ruby silver ore.....	-0.54
Arsenic.....	+0.04	Stephanite...	-0.54
Bismuth.....	.....	Stibnite.....	-0.56
Niccolite.....	-0.11		

<sup>1</sup> PROF. S. B. CHRISTY, *Trans. A. I. M. E.*, Sept., 1899.DECOMPOSITION VOLTAGES OF MOLTEN ALKALI HALIDES AND ALKALINE-EARTH CHLORIDES<sup>1</sup>

Compound	Decomposition voltage	Temp. coeff.
LiCl.....	630° C. = 2.62 v.	1.35 × 10 <sup>-3</sup>
NaCl.....	835° C. = 2.6 v.	1.46 × 10 <sup>-3</sup>
KCl.....	810° C. = 2.8 v.	1.51 × 10 <sup>-3</sup>
NaBr.....	690° C. = 2.45 v.	1.465 × 10 <sup>-3</sup>
KBr.....	690° C. = 2.6 v.	1.455 × 10 <sup>-3</sup>
NaI.....	630° C. = 2.05 v.	1.48 × 10 <sup>-3</sup>
KI.....	630° C. = 2.2 v.	1.48 × 10 <sup>-3</sup>
Na <sub>2</sub> SO <sub>4</sub> .....	890° C. = 2.5 v.	2.00 × 10 <sup>-3</sup>
K <sub>2</sub> SO <sub>4</sub> .....	890° C. = 2.6 v.	2.00 × 10 <sup>-3</sup>
Na <sub>2</sub> CO <sub>3</sub> .....	770° C. = 1.3 v.	.....
CaCl <sub>2</sub> .....	585° C. = 2.85 v.	0.685 × 10 <sup>-3</sup>
SrCl <sub>2</sub> .....	615° C. = 3.0 v.	0.715 × 10 <sup>-3</sup>
BaCl <sub>2</sub> .....	650° C. = 3.05 v.	.....

<sup>1</sup> B. NEUMANN AND E. BERGVE. *Z. Elektrochem.* **21**; 152-60 (1915) — For these experiments a C crucible covered with a mixture of water-glass and asbestos was found to be the only one practicable. Graphite electrodes were used covered, where exposed, with the same mixture.

**Deposition by Immersion<sup>1</sup>**

Solution	Deposits on	Does not deposit on
SbCl <sub>3</sub> .....	Bi, Brass, German Ag, Pb, Sn, Zn.....	Sb, Cu, Fe, Ni, Au, Pt, Ag.
BiCl <sub>3</sub> .....	Fe, Pb, Sn, Zn....	Sb, Bi, Brass, Cu, Au, Pb, Ag.
CuSO <sub>4</sub> , Cu- (NO <sub>3</sub> ) <sub>2</sub>	Fe, Pb, Sn, Zn....	Sb, Bi, Cu, Au, Ni, Pt.
CuCl <sub>2</sub> ....	Bi, Fe, Pb, Sn, Zn..	Sb, Cu, Au, Ni, Pt, Ag.
CuCl <sub>2</sub> (am- moniacal).	Zn .....	Sb, Cu, Au, Bi, Fe, Pb, Ni, Pt, Ag.
HgNO <sub>3</sub> ....	As, Bi, Cd, Cu, Sb, Fe, brass, Pb, Zn	
AgNO <sub>3</sub> ....	Pb, Sn, Cd, Zn, Cu, Bi, Sb, Fe, Ni..	Ag, Au, Pt.
AgNO <sub>3</sub> (alcoholic).	As, Sb, Bi, Zn, Sn, Cu, Fe.	
AgCN·KCN..	Zn, Pb, Cu, brass, German Ag.	{ Sb, Bi, Sn, Fe, Ni, Ag, Au, Pt.
Au(CN) <sub>3</sub> KCN	Zn, Cu, brass, German Ag.	{ Sb, Bi, Sn, Pb, Fe, Ni, Ag, Au, Pt.

**Cleaning Metals by Electrolysis.**—In cleaning adhesions of dirt, rust, etc., from metals, the following method is recommended: The articles are connected to the poles of an alternating circuit and immersed in a salt solution. The liberation of gases on the surface of the metals very quickly removes or loosens everything of a non-metallic character, while the alternating current prevents any permanent action on the metal itself, and it is said the finish of the surface is not interfered with. The voltage should be sufficient to cause evolution of gas at the poles, and currents up to 110 volts have been used. (*Mining Review*, Melbourne, Aust.)

Other authorities recommend a 10 per cent. solution of H<sub>3</sub>PO<sub>4</sub>. A carbon electrode is used if both electrodes cannot be composed of metals to be cleaned.

A mixture of freshly moistened crushed sodium bisulphate and common salt can also be used. This is applied and allowed to remain in contact with the plate to be cleaned for some time. After the plate is clean the mixture should be scraped off and the plate washed with an alkaline solution.

Ten per cent. ferrous sulphate solutions, or 10 per cent. aluminum sulphate solution, or 3½ per cent. boric acid solution is recommended by FRIEND and MARSHALL, allowing about 14 days if solution, for taking off rust.

<sup>1</sup> GORE, "Art of Electrolitic Separation of the Metals."

DIPS FOR COPPER AND BRASS<sup>1</sup>

	Deg. Bé	Sp. Gr.	Scaling dip		Bright dip	
			g. per l.	cc.	g. per l.	cc.
H <sub>2</sub> SO <sub>4</sub> . . . .	66	1.84	700	380	800	435
HNO <sub>3</sub> . . . .	40	1.38	100	72	100	72
HCl . . . . .	21	1.17	5	4	2.5	2
H <sub>2</sub> O . . . . .	..	....	444	444	491	491

<sup>1</sup> A. KENNETH GRAHAM, *Trans. A. E. S.*, 1927, p. 219.

**Electrolytic Rectifier.**—Where only alternating current is available, direct current for storage-battery charging and similar uses may be obtained by running the alternating current through an electrolytic cell consisting of a steel electrode, an aluminum electrode, and a boric-acid electrolyte (Nodon electrolytic valve). Current passes with relative ease from the iron to the aluminum, but not in the reverse direction. Another rectifying cell consists of a plate of tantalum and one of lead immersed in a dilute sulphuric acid solution (U. S. Patent 1,495,582). The output is increased by adding a nickel or iron salt to the electrolyte. The current output is limited by the overheating of the cell. The temperature should not be carried to over 70°C.

## SECTION V

### SAMPLING, ASSAYING AND ANALYSIS<sup>1</sup>

#### STANDARD SOLUTIONS

**Ammonium-nitrate Solution.**—For washing ammonium phosphomolybdate—5 to 10 per cent. Dissolve 50 to 100 grams  $\text{NH}_4\text{NO}_3$  in water and acidify with  $\text{HNO}_3$ , using 1 cc. per liter excess. Or add ammonia to strong  $\text{HNO}_3$  (sp. gr. 1.42) until alkaline to litmus, and bring back to acidity with  $\text{HNO}_3$ , using 1 cc. per liter excess.

**Ammonium-oxalate Solution.**—Used chiefly as a precipitant for calcium. 1 gram of salt per 10 cc. of water. 1 cc. will then precipitate 0.0145 gram of  $\text{CaO}$ .

**Barium Chloride.**—Used as precipitant for  $\text{SO}_3$ . 1 gram of crystals per 10 cc. of water. 1 cc. will precipitate 0.0327 gram  $\text{SO}_3$ .

**Bichromate Solution.**—For iron determination—8.79 grams pure  $\text{K}_2\text{Cr}_2\text{O}_7$  in two liters of water. 1.0 cc. = 0.005 mg. Fe.

**Cochineal.**—Grind 1 gram of the bugs in a mortar and digest with 100 to 150 cc. of cold dilute alcohol (1 vol. alcohol, 3 vol. water) for 20 or 30 min. Filter and the solution is ready for use. See note under phenolphthalein concerning acidity of alcohol. Useful with titrations with ammonia. Salts of copper, iron and aluminum must be removed. Color changes from yellowish red in acids to purple in alkalis.

**Cuprous-chloride Solution (ammoniacal).**—For gas analysis. Weigh out 16 grams of fresh  $\text{Cu}_2\text{Cl}_2$ , or about 25 if it is old. Place in large Florence flask and add 250 cc. water. By means of delivery tube immersed in water, pass the gas from 200 cc. concentrated ammonia water into the  $\text{Cu}_2\text{Cl}_2$  flask using a two-hole stopper in this flask with a check valve. Pass until practically all ammonia has passed over. 100 cc. of this  $\text{Cu}_2\text{Cl}_2$  solution will absorb 24 cc. of CO but should not be used in second pipette after it has absorbed 6.

**Cyanide Solution.**—For copper determination. Use about 23 grams commercial potassium cyanide per liter of water. The theoretical amount is 20.63. 1.0 cc. = 0.005 gram Cu.

**Dimethyl Glyoxime Solution.**—For nickel. Dissolve 10 grams of dimethyl glyoxime in 1 liter of 98 per cent. alcohol and filter, if necessary. Ten cc. precipitate approximately 0.025 grams of nickel.

<sup>1</sup> For data on qualitative analysis see the previous section, pp. 322-343 inc.

The dimethyl glyoxime may be recovered by saving the nickel dimethyl glyoxime precipitates, triturating them with a little water, and rinsing the paste into an evaporating dish with the addition of a little potassium cyanide, until the nickel salt dissolves forming a reddish-yellow solution. Filter the solution, without allowing it to stand, to remove asbestos fibers, etc., allow the solution to cool and saturate it with pure carbon dioxide gas. At the end of an hour all the dimethyl glyoxime will be precipitated. Filter on a suction funnel, wash with cold water, dry and weigh. Dissolve the dry powder in 98 per cent. alcohol 100 cc. per gram of the precipitate, add a pinch of bone black, heat and filter. The solution may now be used as a reagent.

**Ether-hydrochloric Acid, A** (for separating ferric chlorides from the chlorides of manganese, nickel and aluminum).—Add ether gradually to hydrochloric acid of 1.19 sp. gr. until a layer of ether forms on top of the acid. It is advisable to cool the mixture from time to time as the ether is added. 100 cc. of HCl (sp. gr. 1.19) will dissolve about 150 cc. of ether.

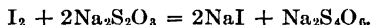
**Ether-hydrochloric Acid, B** (the weak solution for the same purpose).—Add ether gradually to hydrochloric acid of sp. gr. 1.10. About 30 cc. of ether will dissolve in 100 cc. of acid.

**Ferrocyanide.**—For zinc determination—45 grams of pure  $K_4FeCy_6$  per liter of water. 1.0 cc. = 0.010 gram Zn.

**Hydrodisodium Phosphate.**— $HNa_2PO_4$ —used as precipitant for magnesia. 1 gram to 10 cc. of water. 1 cc. of solution precipitates 0.0112 gram of MgO.

**Hyposulphite Solution.**—For use in iodide copper determination—19.59 grams c.p. sodium hyposulphite per liter of water. 1.0 cc. = 0.005 g. Cu.

**Iodine Solution.**—(1 cc. of this solution = 1 cc. of hyposulphite described above.) Dissolve 9.8 grams of iodine in 100 cc. of water containing 20 grams of pure potassium iodide and make up the solution to 1 liter.



**Litmus.**—Dissolve 1 gram of litmus in 100 cc. of hot water and add, drop by drop, dilute sulphuric acid until the liquid acquires a red color. Boil for 10 min. to expel the carbon dioxide. Should the red color pass into blue during the boiling, restore the color by adding a few drops of dilute sulphuric acid. Then add baryta water, drop by drop, until a violet color develops, set aside to deposit, and filter. Preserve the litmus tincture in bottles not completely filled, and preferably covered only with a loose cover.

**Magnesia Mixture.**—Dissolve 3 grams calcined MgO in least necessary quantity HCl. Add excess of magnesia and heat. Filter off any precipitated iron, aluminum or phosphates, and add 35 grams ammonium chloride and 25 cc. of strong ammonia, and dilute to 250 cc. 1 cc. = 0.016 gram  $P_2O_5$  approximately.

**Magnesium-nitrate Solution.**—Dissolve 16 grams calcined magnesia in least necessary nitric acid. Add an excess of magnesia, heat for a few minutes, filter and make up 100 cc.

**Manganese Sulphate Solution.**—For use in iron titrations, to render end-point more distinct. 160 grams of manganous sulphate are dissolved and diluted to 1750 cc. To this are added 330 cc. of phosphoric acid (syrup 1.7 sp. gr.) and 320 cc. of sulphuric acid. About 6 or 8 cc. are used in a titration.

**Mercuric-chloride Solution.**—For tin precipitation in iron analysis—7 gram $\pi$   $\text{HgCl}_2$  in 150 cc. water.

**Methyl Orange.**—Dissolve the dry substance in water, about 0.3 gram per liter. It must be used in cold solutions. It cannot, as a rule, be used with organic acids or with nitrites. Yellow with alkalis, pink with acids.

**Molybdate Solution.**—Dissolve 25 grams molybdic acid ( $\text{MoO}_3$ ) in about 100 cc. ammonia water. If action is too slow, warm and add a little more strong ammonia water. Cool and pour solution, a little at a time, into about 300 cc. of  $\text{HNO}_3$  (sp. gr. 1.20). Cool mixture during this process. Dilute to 500 cc. 1 cc. will precipitate about 0.001 gram of phosphorus.

For lead determination dissolve 9 grams of the salt in 1000 cc. water. 1.0 cc. = 0.01 gram Pb.

**Nessler's Solution.**—For estimation of ammonia in water analysis. Dissolve 50 grams potassium iodide in a small quantity of hot water, cool, and add with frequent agitation a strong solution of mercuric chloride (40 grams of  $\text{HgCl}_2$  to 300 cc. of water until the red precipitate just redissolves. Filter. Add to the filtrate a strong solution of potassium hydrate containing 200 grams of the salt. Filter. Dilute to 1000 cc. and add 5 cc. of a saturated solution of mercuric chloride. Allow the precipitate to settle, decant the clear liquid and keep for use in a tightly stoppered bottle.

**Normal Acid or Alkaline Solutions.**—Contain 1.008 grams of acid hydrogen or 17.008 grams of hydroxyl per liter.

**Permanganate Solution.**—For iron, lime, etc. 12 grams  $\text{KMnO}_4$  to 2030 cc. water. 1 cc. = 10 mg. Fe. The same solution may be used for lime, 1 cc. = 5 mg.  $\text{CaO}$ ; and for Mn, 1 cc. = 0.002946 gram Mn. The decomposition of permanganate solutions can be lessened or entirely avoided by allowing them to stand for a few days, then filtering through glass-wool or asbestos, and then standardizing.

**Phenolphthalein.**—The dry material is dissolved in alcohol, 5 grams per liter. The alcohol may have some acidity which can be removed by boiling, or by redistillation with lime. Cannot be used with ammonia or ammonium salts. Can be used for weak organic acids. Red with alkalis, colorless with acids.

**Platinic Chloride.**—Dissolve 1 gram of metal in *aqua regia*, evaporate to dryness, and dissolve in 1 cc.  $\text{HCl}$  and 9 cc.  $\text{H}_2\text{O}$ . 1 gram of this solution precipitates 0.048 gram of  $\text{K}_2\text{O}$ .

**Salt Solution.**—5.4189 grams per liter. 1.0 cc. = 0.01 mg. of silver. The salt should be dried at about  $125^\circ\text{C}$ .



**Silver Nitrate.**—1 gram per 20 cc. of water. 1 cc. precipitates 0.0104 gram of Cl.

**Sodium Bismuthate.**—This reagent may be prepared by heating 20 parts of caustic soda nearly to redness in an iron or nickel crucible, adding gradually 10 parts dry basic bismuth nitrate, followed by 2 parts of sodium peroxide. Pour the brownish fused mass on an iron plate to cool. When cold, wash four or five times by decantation with water, collect on asbestos filter and dry at 110°C. The compound answers roughly to the formula  $\text{NaBiO}_3$ . It is unstable and if kept over six months, should be retested to see if it retains its oxidizing power. Dark-brown samples appear as efficient as yellow.

**Sodium Chloride.**—See salt solution.

**Stannous Chloride Solution.**—Heat 15 grams  $\text{SnCl}_2$  and 1 gram pure Sn with 40 cc. water and 10 cc. conc. HCl. Keep tightly stoppered as it readily absorbs oxygen.

**Starch Paste.**—Rub 2 or 3 grams of starch with cold water to a smooth paste which is then added a little at a time to 400 or 500 cc. of boiling water into which it should be thoroughly stirred. After several minutes remove from heat and dilute (if necessary) to 600 cc. and add 5 grams of crystallized zinc chloride. Stir until the zinc salt dissolves, then allow to cool and settle. Decant and bottle the clear liquid for use.

**Tannin.**—For use as indicator in lead assay by titration with ammonium molybdate. Dissolve 1 gram of tannin in 300 cc. water.

## COMMON NAMES AND THEIR CHEMICAL EQUIVALENTS

**Alum**—usually potassium aluminum sulphate,  $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$  is meant. The term applies generally to compositions of the type  $\text{R}'\text{R}''(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ .

**Alundum**—electrically fused  $\text{Al}_2\text{O}_3$ .

**Argols**—impure potassium bitartrate from the residues of wine making.

**Baking soda**—sodium bicarbonate,  $\text{HNaCO}_3$ .

**Black ash**—crude soda ash.

**Bleaching powder**— $\text{CaOCl}_2$ .

**Blue mass**—a medicinal preparation of mercury.

**Bluestone** (blue vitriol)—copper sulphate,  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ .

**Borax**—sodium tetraborate,  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ .

**Butter of antimony**—antimony trichloride.

**Calomel**—mercurous chloride,  $\text{HgCl}_2$ .

**Caustic soda**—sodium hydroxide,  $\text{NaOH}$ .

**Choke damp**—black damp; carbon monoxide.

**Chile saltpeter**—sodium nitrate,  $\text{NaNO}_3$ .

**Copperas**—ferrous sulphate,  $\text{FeSO}_4 \cdot 5\text{H}_2\text{O}$ .

**Corundum**—crystallized native alumina.

**Cream of tartar**—acid potassium tartrate.

**Crocus martis**—a polishing powder made by calcining crystals of ferrous sulphate.

**Corrosive sublimate**—mercuric chloride,  $\text{HgCl}_2$ .

**Cupferron**—nitrosophenyl hydroxylamin ammonium.

**Dutch oil**—ethylene chloride,  $\text{C}_2\text{H}_4\text{Cl}_2$ .

**Emery**—alumina, chiefly from the island of Naxos.

**Epsom salts**—magnesium sulphate.

**Eschka's mixture**—magnesium oxide and sodium carbonate.

**Fehling's solution**.—this is prepared by dissolving 34.64 grams of pure crystallized copper sulphate in 500 cc. of water, and 173 grams of potassium sodium tartrate and 50 grams sodium hydroxide, in 500 cc. water. When ready to use, take equal volumes of the two solutions. 1 cc. is equivalent to 0.00475 grams of cane sugar after inversion, 0.005 grams anhydrous glucose, or 0.00678 grams anhydrous lactose.

**Fire damp**—methane.

**Fowler's solution**—a solution of arsenious acid 1, potassium bicarbonate 1, compound tincture of lavender 3, water 95.

**Glauber's salts**—sodium sulphate,  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ .

**Green vitriol**—ferrous sulphate,  $\text{FeSO}_4 \cdot 5\text{H}_2\text{O}$ .

**Hypo**—sodium thiosulphate,  $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ .

**Javelle water**—a dilute solution of potassium carbonate and bleaching powder.

**Laughing gas**— $\text{N}_2\text{O}$ .

**Litharge**—lead oxide,  $\text{PbO}$ .

**Lunar caustic**—silver nitrate,  $\text{AgNO}_3$ .

**Magnesia alba**—magnesium hydroxycarbonate.

**Marignac's salt**—potassium stannosulphate,  $\text{K}_2\text{Sn}(\text{SO}_4)_2$ .

**Marsh gas**—methane,  $\text{CH}_4$ .

**Microcosmic salt**—sodium-ammonium-hydrogen phosphate,  $\text{HNH}_4\text{PO}_4 \cdot 4\text{H}_2\text{O}$ .

**Minium**—red lead,  $\text{Pb}_3\text{O}_4$ .

**Mohr's salt**— $\text{FeSO}_4 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$ .

**Muriatic acid**—hydrochloric acid,  $\text{HCl}$ .

**Mustard gas**—dichloro-diethyl sulphide,  $(\text{CH}_2\text{ClCH}_2)_2\text{S}$ .

**Niter cake**—the residue from nitric-acid making, impure  $\text{HNaSO}_4$ .

**Olefiant gas**—ethylene,  $\text{C}_2\text{H}_4$ .

**Oil of bananas**—amyl acetate.

**Oil of mirbane**—nitrobenzene,  $\text{C}_6\text{H}_5\text{NO}_2$ .

**Oil of mustard**—allyl isothiocyanate,  $\text{CSNC}_3\text{H}_5$ .

**Oil of vitriol**—sulphuric acid.

**Orpiment**—arsenic trisulphide,  $\text{As}_2\text{S}_3$ , as found native.

**Paris green**—aceto-arsenite of copper.

**Pearl white**—a basic nitrate of bismuth used as a cosmetic.

**Pink salt**—a double salt of stannic and ammonium chlorides, used as a mordant.

**Plaster of paris**—calcined gypsum.

**Prussian blue**—ferric ferrocyanide.

**Prussic acid**—hydrocyanic acid,  $\text{HCN}$ .

**Purple of Cassius**—the precipitate produced by adding stannous chloride to auric chloride solution. Probably a colloidal gold.

**Realgar**—red arsenic glass.

**Red lead**— $\text{Pb}_3\text{O}_4$ .

**Red prussiate of potash**—potassium ferricyanide,  $\text{K}_3\text{Fe}(\text{CN})_6$ .

**Rinman's green**—basic phosphate of cobalt and zinc, contains 6 per cent. Co.

**Rochelle salts**—potassium-sodium tartrate,  $\text{KNaC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$ .

**Roman alum**—potassium-aluminum alum.

**Saltpeter**—potassium nitrate,  $\text{KNO}_3$ .

**Salt**—ordinarily sodium chloride is meant.

**Sal prunelle**—purified potassium nitrate moulded into balls.

**Salt cake**—impure sodium sulphate,  $\text{NaHSO}_4$ . (This is a residue from nitric-acid making.)

**Salt of amber**—succinic acid.

**Sal ammoniac**—ammonium chloride,  $\text{NH}_4\text{Cl}$ .

**Salts of lemon**—acid potassium oxalate,  $\text{HKC}_2\text{O}_4$ . Poisonous.

**Salt soda**—(washing soda) sodium carbonate,  $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ .

**Scheele's green**—copper arsenite,  $\text{CuHAsO}_3$ .

**Schiff's reagent**—ammonium thio-acetate solution,  $\text{CH}_3\text{COONH}_4$ .

**Seidlitz powders**—35 grains of tartaric acid and a mixture of 40 grains of sodium bicarbonate with 120 grains of Rochelle salts.

**Soda ash**—sodium carbonate,  $\text{Na}_2\text{CO}_3$ .

**Soda lime**—a mixture (equal molecular parts) of  $\text{NaOH}$  and  $\text{CaO}$ .

**Sodium "hyposulphite"**—sodium thiosulphate,  $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ .

**Soluble water glass**—sodium silicate,  $\text{Na}_2\text{SiO}_3$ .

**Sorensen's oxalate**—sodium oxalate,  $\text{Na}_2(\text{C}_2\text{O}_4)$ .

**Sugar of lead**—lead acetate,  $\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$ .

**Tartar emetic**—potassium-antimony tartrate.

**Thenard's blue**—cobalt oxide and alumina, contains 14 per cent. Co.

**Tincal**—sodium tetraborate,  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ .

**Washing soda**—sodium carbonate.

**Waterglass**—sodium silicate.

**White vitriol**—zinc sulphate,  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ .

**Yellow prussiate of potash**—potassium ferrocyanide,  $\text{K}_4\text{Fe}(\text{CN})_6$ .

## pH

If an acid is mixed with water it is partially dissociated. If we represent by  $[H^+]$  the concentration of the hydrogen ions and by  $[A^-]$  the concentration of the acid ions (in a monobasic acid these would be equivalent) and by  $[HA]$  the undissociated acid, then

$$\frac{[H^+] \times [A^-]}{[HA]} = K_a$$

where  $K_a$  is the so-called ionization or dissociation constant.

Similarly, for bases

$$\frac{[B^+] \times [OH^-]}{[BOH]} = K_b$$

where B is a monoacid base and  $K_b$  its characteristic dissociation constant.

In water, a portion of the water is dissociated and  $\frac{[H^+] \times [OH^-]}{[HOH]} = k$ , but since the concentration of the undissociated water is so large compared with the portion dissociated, the equation may be written

$$[H^+] \times [OH^-] = K_w.$$

In any alkaline solution there are enough hydrogen ions to satisfy the above relation and we may consequently speak of the hydrogen-ion concentration of alkaline solutions.<sup>1</sup>

If  $K_a$  and  $K_b$  are large there must be a relatively large amount of acid or base dissociated. If they are small the amount of dissociation must be relatively small. If the amount of dissociation is taken as a measure of "strength" of the acid or base, then  $K_a$  or  $K_b$  is a measure of this strength.

Rewriting the original equation  $\frac{1}{[H^+]} = \frac{[A^-]}{K_a[HA]}$ , and for convenience we use the equation in reciprocal form and use the value of  $\log \frac{1}{[H^+]}$  under the symbol pH where  $H^+$  is expressed as grams of hydrogen ions per liter.

The hydrogen-ion concentration is becoming of considerable importance commercially. Certain substances will filter, or settle well at a fixed pH concentration.

While the ideal method of determining the pH concentration is by electrometric methods, indicators are certainly more convenient. SORENSON investigated extensively the correspondence between colorimetric and electrometric determinations of hydrogen-ion concentration and found the discrepancies due to proteins and to certain salts. He chose indicators relatively free from salt and protein errors, which are marked\* in the list of indicators on p. 384.

CLARK and LUBS also worked out a number of indicators, some of which, with the method of preparation of the stock solution, are given below.

<sup>1</sup>  $K_w = 10^{-14}$ . If in an alkaline solution the hydroxyl-ion concentration is 0.01N or  $10^{-2}$ , then  $[H^+] \times [OH^-] = 10^{-14}$  or  $[H^+] = \frac{10^{-14}}{10^{-2}} = 10^{-12}N$ .

CLARK and LUBS worked out some standard solutions which give a definite pH value, and which can consequently be used in matching colors for colorimetric determination of pH value.

STANDARD BUFFER SOLUTIONS AT 20°C.  
MAKE UP 50 Cc. A + x Cc. B. DILUTE TO 200 Cc.

A = 0.2M KCl B = 0.2M HCl		A = 0.2M KH o-phthal- ate B = 0.2M HCl		A = 0.2M KH o-phthal- ate B = 0.2M NaOH		A = 0.2M KH <sub>2</sub> PO <sub>4</sub> B = 0.2M NaOH		A = 0.2M H <sub>3</sub> BO <sub>3</sub> * + 0.2M KCl B = 0.2M NaOH	
pH	cc. B	pH	cc. B	pH	cc. B	pH	cc. B	pH	cc. B
1.2	64.5	2.2	46.70	4.0	0.40	5.8	3.72	7.8	2.61
1.4	41.5	2.4	39.60	4.2	3.70	6.0	5.70	8.0	3.97
1.6	26.3	2.6	32.95	4.4	7.50	6.2	8.60	8.2	5.90
1.8	16.6	2.8	26.42	4.6	12.15	6.4	12.60	8.4	8.50
2.0	10.6	3.0	20.32	4.8	17.70	6.6	17.80	8.6	12.00
2.2	6.7	3.2	14.70	5.0	23.85	6.8	23.65	8.8	16.30
		3.4	9.90	5.2	29.95	7.0	29.63	9.0	21.30
		3.6	5.97	5.4	35.45	7.2	35.00	9.2	26.70
		3.8	2.63	5.6	39.85	7.4	39.50	9.4	32.00
				5.8	43.00	7.6	42.80	9.6	36.85
				6.0	45.45	7.8	45.20	9.8	40.80
				6.2	47.00	8.0	46.80	10.0	43.90

\* On basis of atomic weight 11 for boron

For the preparation of these stock solutions, 0.1 gram of the dry powder is ground in a mortar with the following quantities of N/20 NaOH. When solution is complete dilute to 25 cc.

Indicator	pH Range	N/20 NaOH per 0.1 g. reagent, cubic centimeter
Phenol sulfon phthalein.....	6.8-8.4	5.7
Tetra bromo phenol sulfon phthal- ein.....	3.0-4.6	3.0
Ortho cresol sulfon phthalein....	7.2-8.8	5.3
Di bromo ortho cresol sulfon phthalein.....	5.2-6.8	3.7
Thymol sulfon phthalein.....	8.0-9.6	4.3
Di bromo thymol sulfon phthalein	6.0-7.6	3.2
Methyl red . . . . .	4.4-6.0	7.4

Methyl red and propyl red (4.8-6.4) may be conveniently prepared for the tests by dissolving 0.1 gram in 300 cc. alcohol and diluting to 500 cc. with water. Ortho cresol phthalein (8.2-9.8) and phenolphthalein (8.3-10.0) are used in a .02 per cent. solution in 95 per cent. alcohol.

# 384 METALLURGISTS AND CHEMISTS' HANDBOOK

## METHODS FOR PREPARATION OF SOLUTIONS OF COMMON INDICATORS<sup>1</sup>

(Courtesy the Coleman & Bell Company)

Name of indicator, pH range	Amount used, grams	Alcohol, 95%, cubic centimeter	Water, cubic centimeter
Alizarine, <i>y</i> 5.5-6.8 <i>r</i> and <i>v</i> 10.0-12.1	0.5	100	
Alizarine blue S, 12.0-14.0	0.5		100
Alizarine red S, <i>y</i> 3.7-4.2 <i>p</i> ...	1.0		100
Alizarine yellow GG, <i>c</i> 10.0-12.0 <i>y</i>	0.3		1,000
*Alizarine yellow R, <i>y</i> 10.1-12.1 <i>y</i>	0.3		1,000
Alkali blue 6B.....	0.5	100	
*Alpha naphtholphthalein, <i>y</i> 7.3-8.7 <i>b</i>	0.2	150	100
*Alpha naphthylamine azo sulphanilic acid, 3.5-5.7.....	0.1	...	100
*Azolitmin—To prepare solution, dissolve 1.0 gram in 25 cc. N/10 KOH and 75 cc. of distilled water, <i>r</i> 4.5-8.3 <i>b</i> ...			
*Benzeneazobenzylamine, <i>r</i> 2.3-3.3 <i>y</i>	0.5	100	
*Benzene azo alpha naphthylamine, 3.7-5.0 <i>y</i>	0.1	100	
Benzopurpurin, <i>v</i> 2.0-4.0 <i>y</i> ...	0.2	...	100
Carminic acid (cochiseal), <i>y</i> 4.8-6.2 <i>v</i>	0.2	100	
Congo red, <i>b</i> 3.0-5.0 <i>r</i> ...	0.5	10	90
Curcumin (turmeric), <i>y</i> 7.8-9.2 <i>br</i>	0.5	100	
*Dimethylamidoazobenzene, 1.2-2.1	0.05	100	
Diphenylaminoazobenzol, 2.9-4.0	0.5	100	
Erythrosin, <i>v</i> 0.0-3.6 <i>fl</i> .....	0.2	...	100
Ethyl orange, <i>r</i> 2.0-4.0 <i>y</i> .....	0.05	...	100
Ethyl red, <i>r</i> 4.4-6.2 <i>y</i> .....	0.1	300	200
Fuchsin acid.....	0.5	...	100
Gallein, variable, 0-14.0.....	0.5	100	
Haematoxylin, 5.0-6.0.....	0.5	100	
Iodo-eosin, <i>v</i> 0.0-0.3 <i>fl</i> .....	0.2	...	100
Lacmoid, <i>r</i> 4.4-6.2 <i>b</i> .....	0.02	...	100
*Metanil yellow, <i>r</i> 1.2-2.3 <i>y</i> ....	0.05	50	50
*Methyl orange, <i>r</i> 3.1-4.4 <i>y</i> ...	0.1	...	1,000
*Methyl red, <i>r</i> 4.4-6.0 <i>y</i> ....	0.1	300	200
*Methyl violet, <i>y</i> 0.1-3.2 <i>v</i>			500
*Neutral red, <i>r</i> 6.8-8.0 <i>y</i> ...	1.0	500	
Ortho cresol phthalein, <i>c</i> 8.2-9.8 <i>r</i>	0.02	100	
*Para nitro phenol, <i>c</i> 5.0-7.0 <i>y</i>	0.2	100	
Phenacetolin, <i>y</i> 3.0-6.0 <i>r</i>	0.5	100	
*Phenolphthalein, <i>c</i> 8.3-10.0 <i>r</i>	0.02	100	100
Poirrier's blue, <i>b</i> 11.0-13.0 <i>r</i>	0.2	...	100
Resazurin, <i>v</i> 3.8-6.5 <i>v</i>	0.02	...	50
*Rosolic acid, <i>b</i> 7.6-8.0 <i>r</i> ...	1.0	50	
Sives red.....	0.01	100	
Tetrabromphenolphthalein, <i>c</i> 8.0-12.0	0.02	100	
*Thymolphthalein, <i>c</i> 9.3-10.5 <i>b</i>	0.5	100	1,000
*Tropaeolin O, <i>y</i> 11.1-12.7 <i>o</i> ...	0.1	...	50
*Tropaeolin OO, <i>r</i> 1.4-2.6 <i>y</i> ...	0.05	50	1,000
*Tropaeolin OOO, <i>y</i> 7.6-8.9 <i>p</i> ...	3.0	...	
Turmeric, <i>y</i> 7.8-9.0 <i>br</i> .....	0.5	100	
Trinitrobenzene, <i>c</i> 13.0-14.3 <i>o</i>	0.5	100	

<sup>1</sup> The color abbreviations are as follows: *b*, blue; *br*, brown; *c*, colorless; *f*, fades; *fl*, fluorescent; *g*, green; *o*, orange; *p*, pink; *pu*, purple; *r*, red; *v*, violet; *y*, yellow.

\* Reagents marked thus make up SORENSON'S list of approved indicators

For more detailed information\* the reader is referred to: CLARK, "The Determination of Hydrogen Ions," Williams & Wilkins Company, Baltimore, Md.; PRIDEAUX, "The Theory and Use of Indicators," D. Van Nostrand Company, New York City.

### Recovery of Molybdenum from Laboratory Waste

J. A. PRESCOTT suggests a method for the recovery of ammonium molybdate used in phosphate determinations. The method is based upon the fact that if ammonium molybdate is boiled with an excess of acid, molybdic acid is precipitated. All residues, including acid liquors from which the yellow phosphomolybdate precipitate has been removed or alkaline or neutral liquors obtained by dissolving the yellow precipitate in alkali or ammonia and ignited residues, are thrown into a large evaporating dish, which is kept heated in order to concentrate the liquors.

As the liquors are concentrated, molybdic acid is precipitated, and eventually, as there is a preponderance of acid residues, a strong, acid, sirupy liquid is obtained, from which crystals of ammonium sulphate or ammonium nitrate separate on cooling. A certain proportion of phosphomolybdate separates out with the molybdic acid. The whole is filtered, and the yellow molybdic acid is washed with cold water and dissolved in excess of ammonia. To the ammonia solution, magnesia mixture is carefully added until no more phosphate precipitates. The solution is filtered, concentrated to a small bulk (keeping ammonia present in excess) and allowed to crystallize.

The mother liquors are worked up for further quantities of molybdate, and if necessary, the crystals obtained are recrystallized. When a blue color, due to the presence of lower oxides of molybdenum, is produced through allowing the waste liquors to evaporate to dryness and overheating, it may be removed by the addition of hydrogen peroxide.

### Toughening Filter Paper

Dr. CLAYTON BEADLE, describes a useful and simple method of strengthening a filter paper to such an extent that it will withstand the pressure produced by a powerful filter pump.

The paper is folded and fitted into a dry funnel in the ordinary way, and then a few drops of nitric acid of sp. gr. 1.42 are allowed to fall in the apex of the paper cone. The funnel is canted and quickly rotated so as to saturate the free unsupported apex of the cone with the acid, and is then immediately rinsed out under a tap, being filled and emptied from the top repeatedly, and finally rinsed out with distilled water if the presence of tap water is undesirable.

This treatment does not slow the filtering action of the paper; on the contrary, it tends to accelerate it, though treating the paper similarly all over slows the filtering very considerably

—four or five times. The method is credited to E. J. BEVAN, about 40 years ago, but few people seem to know of it.

### Notes on the Use and Care of Platinum Ware<sup>1</sup>

It is important to remember that, although platinum is not oxidized in the air at any temperature, nor attacked by any single acid, yet there are many substances that attack and combine with it at comparatively low temperature.

The caustic alkalis, the alkaline earths, nitrates and cyanides, and especially the hydroxides of barium and lithium attack platinum at a red heat, although the alkaline carbonates have no effect at the highest temperatures. Phosphorus and arsenic attack platinum when heated with it; therefore phosphates, arsenates, etc., should not be ignited in their filter paper in the crucible. Silicon, which may be formed by the reducing action of carbon on silica, causes brittleness. Contact with compounds of easily reducible metals like lead is dangerous at high temperatures, because low-fusing platinum alloys are readily formed. Do not put platinum in the inner cone of the Bunsen flame; the carbon in this cone reacts with the platinum to form a carbide which causes brittleness and general deterioration.

Every careful analyst of necessity uses clean utensils. The habit of cleaning and polishing platinum ware immediately after using is easily formed, and repays the user with increased confidence in his work as well as with the prolonged life of the article.

The loosening effect of the Bunsen flame upon the surface of platinum exposed to its action produces the familiar gray appearance which cannot be removed except by burnishing. Rubbing the surface of platinum with moist sea sand (round grains only), applied with the finger, serves to remove most impurities and to polish the metal, without material loss in weight.

Fusing bisulphate of potash or borax in the vessel and then boiling in water and polishing as above with sand is recommended by GMELIN. When it is desired to clean the outer surface of vessels in this manner, they must be placed in dishes of sufficient size to allow the fused flux to envelope completely the article to be cleaned.

Sodium amalgam possesses the property of wetting platinum without amalgamating with it, even when other metals are purposely added to the amalgam. This substance is, therefore, useful for effecting a quick and thorough cleansing of platinum. The amalgam is gently rubbed upon the metal with a cloth and then moistened with water, which oxidizes the sodium and leaves the mercury free to alloy with foreign metals. The mercury is then wiped off and the article cleaned and polished with sand, as above described.

<sup>1</sup> Courtesy BAKER & Co., Newark, N. J.



If the existence of a base metal alloyed with the platinum is suspected, immerse the article in question first in boiling hydrochloric acid for a few minutes; then, after thoroughly rinsing with clean water, in boiling nitric acid free from chlorine. If the article is unaffected in weight or appearance, and the acid baths fail to give reaction for base metals, the absence of such is assured.

### The Preparation of Proof Gold<sup>1</sup>

The purest gold which can be obtained (usually assay cornets) is dissolved in *aqua regia* and the excess of nitric acid expelled by repeated evaporation with additional hydrochloric acid on a water bath. The final solution is then poured in a thin stream into a large beaker full of distilled water, producing a solution of about 1 oz. of gold per pint of water. Stir vigorously and leave the solution to settle. At the end of about a week the chloride of silver will have subsided to the bottom. Remove the clear supernatant liquor with a glass siphon and dilute to about 1 oz. of gold per gallon of water. If the gold originally used was free from platinum, precipitate with sulphurous acid; if platinum was present, precipitate with oxalic acid. Sulphurous acid acts almost immediately, but if oxalic acid is used the solution should be warmed and allowed to stand for 3 or 4 days.

After the precipitated gold has settled the acid solution is siphoned off and the gold transferred to a large flask and repeatedly shaken with cold distilled water, closing the mouth of the flask with a watch-glass. The gold is then washed thoroughly with hot water and turned out into a porcelain basin, dried and melted in a clay crucible and poured into an iron mould, which should be neither smoked nor oiled, but rubbed with powdered graphite and then brushed clean with a stiff brush. The ingot is cleaned by brushing and heating in hydrochloric acid. It is then dried and rolled out. The rolls must be clean and bright and free from grease. The surface of the rolled gold plate is then cleaned by scrubbing with fine sand and ammonia, and also with hydrochloric acid, and is scraped with a clean knife before being used for proof in the *brillon assay*.

Another method is given in the Memorandum by the Assayers of the Melbourne Mint, in the "Annual Report of the Mint," 1913, p. 138. Cornets of gold, derived from the metal obtained by reduction with sulphurous acid, and containing 0.1 per cent. of impurity (chiefly Ag), were treated with cold *aqua regia* (4:1), the solution largely diluted and allowed to stand for a week to effect separation of silver chloride. Three successive quantities of a dilute solution of silver nitrate (containing Ag 0.5 grain) were then added at intervals of 3 days, the surface of the liquid being gently stirred after each addition, and the whole was allowed to stand for 14 days. Any iridium or other impurity suspended in the liquid was entangled in the precipitated silver chloride; the clear solution was siphoned off,

<sup>1</sup> T. K. Rose, "Metallurgy of Gold," 5th ed., p. 488.

evaporated to dryness and ignited in porcelain; the sponge gold fused in a clay crucible with potassium bisulphate and nitrate, borax added, the melt allowed to cool, the cone of gold treated with boiling hydrochloric acid to remove adhering slag, placed by hand upon borax-glass contained in a clay crucible within a large, covered guard-pot, and melted under conditions precluding contamination of the metal by furnace dust. A slow current of chlorine was then passed through the molten metal for 1 hour, the gas being conducted through a clay tube ( $\frac{1}{8}$ -in. bore) by which the gold was continuously stirred. The charge was allowed to cool in the crucible, the cone of gold treated with boiling hydrochloric acid and finally rolled (with special precautions against contamination) into a fillet which was also treated with boiling acid. The original gold weighed 21.5 oz., the finished fillet 21.28 oz., and 0.204 oz. was subsequently recovered from the slag.

### The Preparation of Proof Silver

Dissolve commercial fine silver in dilute nitric acid (1:1), and allow the liquid to stand until any fine gold has settled. Siphon off from the gold, dilute with hot water, precipitate the silver with hydrochloric acid, stir well, allow to settle, and wash thoroughly by decantation. When the decanted liquid no longer shows hydrochloric acid, which can be ascertained by testing it with a little silver nitrate, it may be considered clean. Allow the silver chloride to settle and decant off the solution. Transfer the silver chloride to a porous cup which has been soaked in hydrochloric acid and thoroughly washed afterward by standing in frequently changed distilled water. A cathode of pure silver or platinum is placed in the silver chloride and the porous cup immersed in a deeper one, in which a carbon anode is placed. Then a current is started, and silver chloride begins to reduce at the cathode. The outer liquid will become saturated with chlorine and should be renewed from time to time. The silver may then be melted down and rolled as given above under the head of gold. Another method is to use the best obtainable fine silver melted into the form of a cathode about 6 or 8 in. long, about 2 in. wide and  $\frac{1}{4}$  to  $\frac{3}{8}$  in. thick. Wrap this in filter paper so that no gold can be detached under electrolysis. The electrolyte is about a 4 per cent. solution of silver nitrate slightly acidulated, and the cathode is pure silver. The current density should be such that the silver is deposited in the form of crystals, which should be later removed, melted and cast, although these crystals may be used themselves in the bullion proof. Still another method of preparing fine silver due I believe, to A. E. Knorr, is to prepare a solution of silver nitrate from the best commercial fine silver obtainable (material which is already 999 fine) evaporate to remove the excess of nitric acid, and to the neutral solution add enough sodium carbonate to precipitate about one-tenth of the silver present. Boil the precipitate and solution thus produced for some time.

The silver carbonate first formed precipitates all other impurities. Allow to settle, decant carefully (or filter).

The remainder of the silver is then precipitated by chemically pure sodium carbonate. This precipitate carries down a considerable amount of sodium carbonate, but when the material is melted down all of the sodium carbonate comes to the surface as a slag, and can be dissolved off with hydrochloric acid later. The silver carbonate will decompose without the addition of any other reagent if heated sufficiently. The bar produced in this way should be, as said above, cleaned with hydrochloric acid and then rolled, as given above under the head of the preparation of proof gold.

### Assay Fluxes

**Basic.**—*Sodium carbonate* ( $\text{Na}_2\text{CO}_3$ ).—Best used in the anhydrous form.

*Sodium Bicarbonate* ( $\text{HNaCO}_3$ ).—Less convenient than the above as it carries much less soda for the same bulk.

*Potassium Carbonate* ( $\text{K}_2\text{CO}_3$ ).—A mixture of sodium and potassium carbonates fuses at a much lower temperature than does either one alone.

*Litharge* ( $\text{PbO}$ ).—Forms exceedingly fusible silicates. Gives metallic lead with reducing agents, C, S, etc.

*Red Lead* ( $\text{Pb}_3\text{O}_4$ ).—Same as above, but is more of an oxidizing agent. Carries silver into slag unless completely decomposed.

*Lead Peroxide* ( $\text{PbO}_2$ ).—Still more energetic oxidizer.

*Hematite* ( $\text{Fe}_2\text{O}_3$ ).—Extremely infusible and must be reduced with carbon in presence of silica in order to work as a flux.

*Lime* ( $\text{CaO}$ ).—When used with silica and some other base it forms fusible slags.

*Sodium Hydrate* ( $\text{NaOH}$ ).—Used chiefly to decompose sulphides and sulphates, certain silicates and oxides, and organic compounds.

**Acid.**—*Borax* ( $\text{Na}_2\text{B}_4\text{O}_7$ ).—Should be fused before use to render it anhydrous. Has the property of holding almost all oxides in suspension.

*Silica* ( $\text{SiO}_2$ ).—Occasionally used with basic ores to lessen corrosion of crucibles. Better to use glass which carries about 80 per cent.  $\text{SiO}_2$ .

*Glass.*—See silica.

**Neutral.**—*Fluorspar* ( $\text{CaF}_2$ ).—Is extremely fusible, and readily carries phosphates, etc., in suspension.

*Common Salt.*—Also very fusible but does not dissolve infusible substances readily. Is mainly used as a cover to prevent oxidation of the charge underneath.

**Metallic.**—*Iron.*—Often used in the form of nails to take care of sulphur.

*Lead.*—Used in scorification assay both as a collector of the precious metals and, as it oxidizes, to take care of the gangue. In the crucible assay it is reduced from some oxide as a collector.

**Oxidizing.**—*Niter* ( $\text{KNO}_3$  or  $\text{NaNO}_3$ ).—At about red heat niter decomposes into potassium nitrite and oxygen,  $\text{KNO}_3 = \text{O} + \text{KNO}_2$ , at a higher temperature the nitrate also decomposes,  $2\text{KNO}_3 = \text{K}_2\text{O} + 2\text{NO} + \text{O}$ .

*Lead Peroxide* (see under *Basic Fluxes*).

**Manganese Dioxide.**—Must be used with some other base, and if any remains undecomposed it appears to carry silver into the slag.

**Sodium Peroxide.**—Extremely energetic and forms very fusible slags. Especially good in decomposing tin ores, and sulphides, antimonites, etc.

### Approximate Reducing Effect of Various Reducing Agents<sup>1</sup>

Reducing agent	Quantity of lead in grams reduced from litharge <sup>2</sup> by 1 gram of reagent
Wood charcoal . . . . .	22-30
Powdered hard coal . . . . .	25
Powdered soft coal . . . . .	22
Powdered coke . . . . .	24
Argol (crude tartar) . . . . .	5 - 9.5
Cream of tartar . . . . .	4 5- 6.5
Wheat flour . . . . .	10 0-12.0
Starch . . . . .	11.5-13.0
Sugar . . . . .	12.0-14.5
Potassium cyanide . . . . .	6
Antimonite . . . . .	6
Blende . . . . .	7-8
Copper pyrites . . . . .	7-8
Fahlerz . . . . .	7-8
Galena . . . . .	3
Iron pyrites . . . . .	11
Mispickel . . . . .	7-8

<sup>1</sup> E. A. SMITH'S, "Sampling and Assay of the Precious Metals."

<sup>2</sup> For amount of lead reduced from red lead multiply the factors given by 0.55.

### In Assay Ton Charges

6 per cent. FeS	reduces a 15-gram button.
8 per cent. ZnS	reduces a 15-gram button.
7 per cent. $\text{CuFeS}_2$	reduces a 15-gram button.
13 per cent. $\text{Cu}_2\text{S}$	reduces a 15-gram button.
20 per cent. PbS	reduces a 15-gram button.

### Oxidizing Agents (Wet)

**Ammonium Nitrate.**—Readily decomposes on heating.

**Bichromates.**—Usually used as the potassium salt.

**Bromine.**—Usually used as liquid.

**Chlorine.**—Generated from bleaching powder and sulphuric acid.

**Chromates.**—Usually used as the potassium salt.

**Chlorates.**—The sodium or potassium salt is used both in fusion and solution.

**Hydrogen Peroxide.**—A powerful oxidizer both in alkaline and acid solution.

**Nitrates.**—The sodium, potassium and ammonium salts are used.

**Nitric Acid.**—An extremely powerful reagent. The fuming acid is still more so and should be kept in a cool, dark place and handled carefully.

**Permanganate.**—The alkali-metal permanganates are energetic oxidizers both in acid and alkaline solution.

**Peroxides** (See also Hydrogen Peroxide).—Sodium and potassium peroxide are energetic agents in alkaline solution. The barium, manganese, lead and sodium peroxides are often used advantageously in fusion.

### Reducing Agents

The chief reduction agents in fusions have been spoken of on p. 390. In solution we may use:

**Alkaline.**—Sodium amalgam, zinc dust, sodium sulphite, sugar, arsenious acid, sodium stannite.

**Acid.**—Zinc, iron, tin, aluminum, lead, stannous chloride, sulphur dioxide, sulphuretted hydrogen, hypophosphorous acid, oxalic acid, ferrous sulphate.

### NITER REQUIRED TO OXIDIZE 1 PART OF METALLIC SULPHIDE

	Sulphide	Parts niter to 1 of sulphide
Iron pyrites.....		2 -2½
Mispickel, copper pyrites, fahlerz, blende.....		1½-2
Antimonite.....		1½
Galena.....		2/3

### STOCK FLUXES

	Sulphide ores	Tellurides		Blende	Tin ores
		I	II		
Litharge.....	8	10	30	50	60
Niter.....	1½			20	
Potass. carb.....			7		
Sodium carb.....	3	3	6	20	40
Borax glass.....	1½	6	5½	15	10
Sand.....	1½			5	
Charcoal.....		0.11			1.5
Flour.....			1		
Cover.....	Salt	Litharge	Litharge	Borax	Soda
Amount for ½ a.t. charge....	8 a.t.	150 grams	75 grams	75 grams	125 grams

TABLE OF CRUCIBLE CHARGES<sup>1</sup>

Ore	Character of slag	A. t. ore	Grams lead flux	Grams $\text{Na}_2\text{CO}_3$	Grams $\text{PbO}$	Grams $\text{K}_2\text{FeO}_4$	Grams $\text{KNO}_3$	Grams $\text{SiO}_2$	Grams argol	Loop of iron wire	Grams borax glass	Cover	Remarks
Oxidised.....	Neutral, no Pb	$\frac{1}{2}$	30	.....	25	.....	.....	.....	.....	.....	.....	Borax	
Quartz.....	No bases	$\frac{1}{2}$	.....	.....	75	.....	.....	.....	2	.....	.....	Borax	
Quartz.....	No bases	$\frac{1}{2}$	30	30	20	.....	.....	.....	.....	.....	.....	Salt	
Oxidised.....	Basic, no Pb	$\frac{1}{2}$	30-40	.....	20	.....	.....	15	.....	.....	.....	Borax	
Oxidised.....	Basic, with $\text{BaSO}_4$	$\frac{1}{2}$	40	20	25	.....	.....	15	.....	2	.....	Borax	
Galena.....	Lead, 84 per cent	$\frac{1}{2}$	20	.....	.....	10	.....	.....	.....	.....	.....	Salt	Heat gradually until mass subsides.
Galena.....	Siliceous, Pb 42 per cent	$\frac{1}{2}$	15	20	20	.....	5	.....	.....	.....	.....	Salt	
Lead carbonate	Neutral, Pb 40 per cent	$\frac{1}{2}$	30	10	15	.....	.....	.....	.....	.....	.....	Borax	
Iron pyrites.....	None	$\frac{1}{2}$	.....	35	20	.....	5	15	.....	6	.....	Borax	Collect matte and scorify with the lead button.
Copper pyrites.....	Iron pyrites	$\frac{1}{2}$	.....	35	30	.....	5	15	.....	6	.....	Borax	Nails if necessary.
Zinky ore.....	.....	$\frac{1}{2}$	.....	40	23	.....	.....	.....	0-3	.....	15	.....	Wet-and-fire method preferable for silver.
Lead matte.....	.....	$\frac{1}{2}$	15	30	20	.....	5	15	.....	5	.....	Borax	Wet-and-fire method preferable for silver.
Copper matte.....	.....	$\frac{1}{2}$	15	30	35	.....	5	15	.....	5	.....	Borax	Wet-and-fire method preferable for silver.
Tellurides.....	Siliceous	$\frac{1}{2}$	30	30	40-80	.....	.....	.....	.....	.....	.....	Salt	Scorification preferable.
Tellurides.....	Siliceous	$\frac{1}{2}$	.....	15	30	.....	.....	.....	2	.....	.....	Salt	Scorification preferable.
Arsenical.....	.....	$\frac{1}{2}$	.....	.....	.....	17	.....	.....	.....	.....	.....	Salt	Scorification preferable.
Slags.....	.....	1	20	40	10	.....	.....	.....	.....	.....	10	.....	Scorification preferable.

Litharge Required to Flux Metallic Oxides<sup>2</sup>

One part of.....	$\text{As}_2\text{O}_3$	$\text{Cu}_2\text{O}$	$\text{CuO}$	$\text{Fe}_2\text{O}_3$	$\text{Sb}_2\text{O}_3$	$\text{ZnO}$	$\text{Fe}_2\text{O}_3$	$\text{MnO}$	$\text{SnO}_2$
Requires parts of PbO.....	1	1.5	1.8	4	5	8	10	10	13

<sup>1</sup> FURMAN, "Manual of Assaying."  
<sup>2</sup> HOFMAN, "Metallurgy of Lead."

## Cupel Absorption

A safe table for cupel absorption of lead buttons is given in ERNEST A. SMITH'S "Sampling and Assay of the Precious Metals," if there is no great departure from a ratio of height to diameter of 3:4.

Diameter of cupel, in. ....	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$
Absorption in grams. ....	3	5	8	10	16	20	28	40

As to the cupel absorption of silver and gold, it seems unsafe to give any tables, as this varies with the nature of the material cupeled, the temperature, whether induced draft is used or not, and many other factors. It seems fairly safe to say that a small silver button will lose about 2 per cent., that at 100 mg. the loss will be about 1.5 per cent. and less for larger buttons, and that the gold loss will probably not run over 0.5 per cent., but these figures must be taken as approximations only. It must also be remembered that not all of the button remaining in the cupel is gold and silver. I have usually found about 0.3 per cent. of Pb and Bi as impurity in the silver button; with cement cupels I have found as much as 0.8 per cent. Pb and Bi. The factor is usually neglected in working on comparative tests on different cupels, although both DEWEY and I have repeatedly pointed it out.

W. J. SHARWOOD states (*Trans. A. I. M. E.*, 1915, page 1484) that "when a given amount of silver (or of gold) is cupeled with a given amount of lead, under a fixed set of conditions as to temperature, etc., the apparent loss of weight sustained by the precious metal is directly proportional to the surface of the button of fine metal remaining." From this he deduces that "the loss of weight varies as the  $\frac{2}{3}$  power of the weight, or as the square of the diameter of the button. The percentage loss varies inversely as the diameter of the button, or inversely as the cube root of the weight." This means that, if we run proof assays of any weight whatever, we can deduce the loss of a button of any other weight.

LEAD RETAINED IN THE CUPELLATION OF PLATINUM ALLOYS<sup>1</sup>

Composition of alloy			Lead retained, mg.	Character of button
Pt, mg.	Ag, mg	Au, mg.		
100	.....	.....	37.5	Hard silvery.
100	25	.....	31.0	Hard silvery.
100	50	.....	26.2	Dull gray.
100	100	.....	25.0	Dull gray.
100	101	48.0	24.0	Dull gray.
100	206	48.0	22.0	Smooth silvery.
100	206	6.0	10.0	Smooth silvery.
100	310	.....	10.0	Slightly crystallized.
100	427	.....	5.0	Smooth and silvery.
100	470	19.4	2.0	Smooth and silvery.

<sup>1</sup>The lead is almost eliminated with 10 parts of silver to 1 of platinum.

<sup>1</sup> W. J. SHARWOOD, *Journ. Soc. Chem. Ind.*, Apr. 30, 1904, p. 413.

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## PARTING OF GOLD-SILVER ALLOYS IN NITRIC ACID<sup>1</sup> (AFTER H. CARMICHAEL.<sup>2</sup>)

Weight of metals used, milligrams			Ratio of metals			Weight of cornet, <sup>3</sup> Au+Pt	Weight of Pt in cornet <sup>3</sup>
Pt	Au	Ag	Pt	Au	Ag		
20	100	300	1	5	15	102.7	2.7
15	100	400	1	6.6	26.6	101.2	1.2
						100.2	0.2
10	100	300	1	10	30	100.8	0.8
						100.4	0.4
10	100	500	1	10	50	100.2	0.2
10	200	600	1	20	60	100.0	0.0
14	200	800	1	14.3	57.1	200.3	0.3
14	300	900	1	21.4	64.3	300	0.0
7	100	400	1	14.3	57.1	100.2	0.2
5	100	500	1	20	100	100	0.0

<sup>1</sup> The first acid was of 1.16 sp. gr., the second of 1.26.

<sup>2</sup> Taken from SMITH's "Sampling and Assay of the Precious Metals" as were also the next two tables.

<sup>3</sup> The author seems to assume a 100 per cent. gold recovery. This is by no means a sure matter, and all the errors of work are thrown on the results for platinum, which are therefore open to suspicion.

## SOLUBILITY OF PLATINUM-SILVER ALLOYS IN NITRIC ACID

Composition of alloy		Parted in HNO <sub>3</sub> of 1.10 sp. gr.		Parted in HNO <sub>3</sub> of 1.40 sp. gr.	
Pt, per cent.	Ag, per cent.	Platiniferous residue, <sup>1</sup> per cent.	Pt dissolved, <sup>2</sup> per cent.	Platiniferous residue, <sup>1</sup> per cent.	Pt dissolved, <sup>2</sup> per cent.
0.5	99.5	0.42	0.08	0.22	0.28
1.0	99.0	0.85	0.15	0.42	0.58
2.0	98.0	1.74	0.26	1.09	0.91
3.0	97.0	2.19	0.81	1.81	1.19
4.0	96.0	2.98	1.02	2.42	1.58
5.0	95.0	3.56	1.44	2.62	2.38
10.0	90.0	.....	.....	4.53	5.47
13.0	87.0	3.33	9.67	5.79	7.21
14.0	86.0	4.26	9.74	4.97	9.03
15.0	85.0	4.32	10.68	7.93	7.07
16.0	84.0	4.55	11.45	11.54	4.46
18.0	82.0	4.53	13.46	11.65	6.35
20.0	80.0	.....	.....	13.94	6.06
25.0	75.0	16.62	8.38	20.66	4.34
30.0	70.0	.....	.....	29.29	0.71
31.5	68.5	33.58	2	.....	.....

<sup>1</sup> Contains Pt and Ag.

<sup>2</sup> Apparently these figures were arrived at by difference and they are probably unreliable for large weights of residue. See the table following.



**SOLUBILITY OF PLATINUM-SILVER ALLOYS IN NITRIC ACID OF  
1.10 SP. GR. (THOMPSON AND MILLER'S TABLE)<sup>1</sup>**

Composition of alloy		Total residue, per cent.	Silver in residue, per cent.	Platinum in residue, per cent.	Platinum dissolved, per cent. <sup>1</sup>
Pt, per cent.	Ag, per cent.				
10.39	89.61	3.86	0.27	3.59	6.80
20.59	79.41	8.58	1.81	6.77	13.82
31.46	68.54	36.59	12.09	24.50	6.96
37.89	62.11	49.13	13.64	35.49	2.40
57.05	42.95	65.16	12.19	52.79	4.08

<sup>1</sup> The solubility of these platinum-silver alloys seems to depend upon the strength of acid used, how the alloy has been annealed, and the amount of gold present, if any.

### Highly Refractory Crucibles

According to DEVILLE a particularly refractory crucible can be made by heating alumina and strongly ignited marble in equal proportions to the highest temperature of the wind furnace, and then using equal proportions of the substance thus obtained with powdered ignited alumina and gelatinous alumina.

Lime crucibles are made by taking a piece of well-burned slightly hydrated lime, cutting it by means of a saw into a rectangular prism 3 or 4 in. on the side and 5 or 6 in. high. The edges are rounded off, and a hole is bored in the center.<sup>1</sup>

To produce thin-walled products from refractory oxides, according to E. PODSZUS, (*Chem. Abs.*, Apr. 20, 1918, p. 857) oxides of the rare earths or Al, Si, Mg, Th, Zr, and the like, are employed, without the use of clay. The material is brought into the state of a freely flowing slurry, consisting of the required amount of liquid, an amount of binder sufficient to give strength when dry, and an extremely finely divided powder of about 0.005 mm. diameter. This mass is applied in one or more layers, by dipping, coating, pouring, spraying, sprinkling, or the like, over a refractory non-porous form which has been coated with a filler, so that the product can be removed without injury from the form. Gelatin, tragacanth, albumin, shellac, varnish, collodion, and the like may be employed for this purpose. To obtain pure products, slowly decomposing salts of the materials used (*e.g.*,  $\text{Th}(\text{NO}_3)_4$  for the production of  $\text{ThO}_2$ ) may be employed. Tubes and the like with walls 0.1 mm. thick can be made in this manner according to this authority.

**Magnesia Crucibles.**—GEORGE WEINTRAUB<sup>2</sup> of the General Electric Company, of Schenectady, N. Y., makes refractory

<sup>1</sup> SEXTON, "Fuel and Refractory Materials."

<sup>2</sup> *Metallurgical and Chemical Engineering*, Vol. 10, p. 308.

articles of magnesia, alumina, thoria, etc., without the use of a binder. The magnesium oxide is first heated in an electric furnace to a high temperature in order to let it assume a stable condition. This firing causes the magnesia to cake together so that regrinding is necessary. It is ground to the fineness of flour in a tube mill. A mould is then made for the article to be produced, say, a crucible. This mould is made of carbon or graphite and a layer of the powdered magnesia is placed on the bottom. A carbon or graphite plug is now placed centrally in the crucible upon this magnesia layer. It is surrounded by a layer of paper which permits the magnesia to shrink when heated. When moulding a crucible of  $2\frac{1}{2}$  in. inside diameter, a paper of from  $\frac{1}{16}$  to  $\frac{1}{8}$  in. thickness is suitable. The space between the walls of the mould and the paper-covered core is then filled with magnesia powder and packed to a certain degree by shaking and bumping. The mould is now placed in an electric furnace and heated to about  $1500^{\circ}\text{C}$ . When finished and the mould is cooled, the walls of the magnesia crucible contract upon the layer of loose paper carbon, so that cracking is avoided. The finished crucibles are smooth, homogeneous and strong and may be safely handled and may even be worked on the lathe. Tubes may be made in the same way.<sup>1</sup>

**Zirconia Crucibles.**<sup>2</sup>—In the production of refractory articles, such as crucibles, zirconia is fused in an arc furnace at 50 amps., 220 volts, and afterwards ground in a ball mill. The powder is then molded or pressed into the required shape with or without an organic bond (as starch), for by grinding a portion to 200 mesh it becomes colloidal in the presence of water, and in that state can be used as a plastic cement for binding the bulk. After gradually drying, the articles are burned at  $2300$  to  $2400^{\circ}\text{C}$ ., till contraction ceases, in a cylindrical oven of the injector type, the fuel being either gas, petroleum, or acetylene supplied with a blast of air and finally with one of oxygen. The crucibles should give a clear ring when tapped, and have as fine a texture as porcelain. Fused zirconia has a high thermal endurance, is not affected when heated to redness and plunged into cold water, its coefficient of expansion being extremely low— $0.00000084$ . Its resistance to crushing strains is many times greater than that of quartz glass. Its hardness is between that of corundum and quartz; its porosity below 1 per cent. The melting-point is  $2950^{\circ}\text{C}$ ., but 0.5 per cent. impurity reduces that by  $100^{\circ}\text{C}$ . In a crucible of fused zirconia, platinum (m.p. about  $1753^{\circ}\text{C}$ .) can be melted to a mobile liquid. It is also claimed that crucibles made from  $\text{ZrO}_2$ , mixed preferably with 1 per cent. starch and 3 per cent. magnesia, and fired first at  $1450^{\circ}\text{C}$ . and then at  $2200^{\circ}\text{C}$ . in a vacuum electric furnace, have been successfully used in determining the boiling point of pure iron and for forming tungsten alloys.

<sup>1</sup> U. S. Patent, 1,022,011, April 2, 1912

<sup>2</sup> *Mineral Foot-Notes*, July and August, 1918. See also page 555.

Crucibles from Tungsten Powder<sup>1</sup>

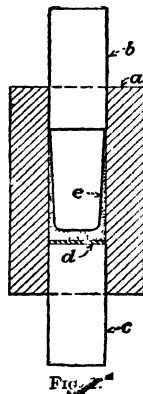
With the advance of high-frequency heating, now popular in high-temperature research, there has been need of a crucible or container with a fairly good electrical conductivity, and a high melting point, but containing no free carbon—which would react with the melt—i.e., a suitable substitute for graphite. The author, having been working for some time with a high-frequency melting equipment, the capacity of which was limited, found some difficulties in obtaining uniform melts of iron alloys, due to the bridging over of a part of the melt at the top of the crucible. This is entirely overcome by the methods to be described.

Ordinary commercial tungsten powder of good quality (98.5 to 99.0 per cent. metallic tungsten, chief impurity being tungstic oxide), ground to 80 to 90 mesh, is used as raw material. A suitable quantity is placed in a flat porcelain mortar and sprinkled with a small quantity of lukewarm water and well mixed; after this, about 10 to 12 per cent. of a warm solution of 25 per cent. glucose in water is gradually added, while the mass is vigorously kneaded until it feels plastic and can be pressed into balls.

It is essential that each particle of tungsten powder be well coated with a film of glucose solution, as otherwise the finished article will show cracks. For this reason it is better to add a slight surplus of glucose, and stamp the mass (after being well kneaded) in a tubular mold and extrude, after which it is slightly heated (to about 60 to 80°C.) for a few minutes on an iron plate. Other binding substances were also tried, such as starch, gum tragacanth and dextrin, but glucose was found to work best.

After this preparation, which makes the mass more plastic, this now semi-plastic mass is placed in a mold, which, for crucibles, is shaped as shown in Fig. 1, in which *a* is a cylinder of cast iron or steel, *b* a pestle slightly cone-shaped, *c* a counter-pestle. The mold should be slightly greased with oil, glycerine or fish glue. The mold is placed with pestle *b* downwards on the table, the mass tamped in, filling the space *e*, preferably with a piece of iron pipe. Between the mass and the pestle *c* a tight-fitting steel plate *d* is placed, preferably also a disk of thin paper which is necessary as the removal of the crucible from pestle *c* is difficult and may spoil the appearance. The mold is placed in a press, giving about 25 to 50 kg. per sq. cm. Hammering with a large hammer is sufficient, if no press is available.

It is not advisable to place the mass in a lump on top of pestle *c* and try to force down the pestle *b* since the mass is too gritty to yield. Pestle *b* is now withdrawn by turning and the



<sup>1</sup> J. HARDEN, *Chem. and Met. Eng.*, September, 1926.

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crucible pushed out and set on a plate to dry. The plate is gradually heated to about 350 to 400°C.

In this condition, the material is comparatively hard and may be handled safely. If heated to about 600°C. in a non-oxidizing atmosphere and cooled, it may be drilled, filed, and turned in the lathe, even screws may be cut if some care is taken, although it is still brittle.

The molded article is now placed in a carbon-tube furnace and fired to at least 1600°C., when it becomes hard and durable. The hardness is varying—the grains being very hard—so that the edge will easily scratch glass.

The formation of tungsten carbide is dependent on the time of heating, as will be shown, as well as on the temperature. According to some investigations by A. WESTGREN and others, MENNICKE (*Die Metallurgie des Wolframs*, 1911, p. 261, Berlin), the lower carbide containing about 3.1 per cent. carbon is quickly formed by heating to about 1500°C., while the higher carbide, containing about 6 per cent. C, forms by prolonged heating.

The articles show a grey metallic color; when ground on an emery wheel, the surface shows a bright metallic luster intermingled with darker spots. The shrinkage from unfired to fired state varies somewhat with the pressure applied, but shows an average of 1.6 per cent. When heated for 20 min. at 1650°C., the average specific gravity was found to be 12.82; when heated for 2.5 hr. at 1600 to 1800°C., the specific gravity was in average 12.21, which indicates the formation of the higher carbide. The specimens were coated with a thin film of solid paraffin before immersion in water for specific gravity test.

If the theoretical specific gravity of the carbide WC is given as 15.7 and  $W_2C$  as 16.06 or a mean value of 15.38 for both, the apparent density of the material described would amount to 83.3 and 79.4 per cent., respectively, dependent on the time and degree of heating. See WILLIAMS, *Compt. rend.*, 1898, Vol. 126 p. 1722, also H. MENNICKE, *loc. cit.*, p. 261.

ANALYSES OF GRAPHITE CRUCIBLES<sup>1</sup>

	1	2	3	4	5	6	7	8
SiO <sub>2</sub> .....	25.91	27.22	33.44	34.03	32.67	37.09	31.40	31.31
Al <sub>2</sub> O <sub>3</sub> .....	11.26	{ 7.03 }	15.70	12.95	{ 11.52 }	14.58	{ 19.57 }	17.30
Fe <sub>2</sub> O <sub>3</sub> .....	0.48	{ 0.51 }			{ 2.79 }		{ 1.78 }	
Ca, Mg, O <sub>2</sub> .....	tr	tr					1.10	
Graphite.....	58.24	62.54	48.15	50.18	48.68	44.40	42.08	47.40
Water.....	2.77	2.42	0.77	1.63	1.50	2.92	1.20	3.42
	98.86	99.72	98.06	98.79	97.16	98.99	97.13	99.43

<sup>1</sup> KERL, "Handbuch der gesamten Thonwaren Industrie."

1, 2, HESSE; 3, RHENISH; 4, DUSSELDORF; 5, German crucible after 18 heats; 6, London (MORGAN); 7, English; 8, American.

# Sampling<sup>1</sup>

## WEIGHTS TO BE TAKEN IN SAMPLING ORE<sup>1</sup>

Weights		Diameters of largest particle					
Grams	Pounds	Very low grade of uniform ores, mm.	Low grade ores, mm.	Medium ores		Rich ores, mm.	Rich and spotty ores, mm.
				Mm.	Mm. #		
.....	20,000 0	207.0	114 0	76.2	50.8	31.6	5.4
.....	10,000.0	147.0	80.3	53.9	35.9	22.4	3.8
.....	5,000 0	104.0	56.8	38.1	25.4	15.8	2.7
.....	2,000 0	65.6	35.9	24.1	16.1	10.0	1.7
.....	1,000 0	46.4	25.4	17.0	11 4	7.1	1.2
.....	500.0	32.8	18 0	12 0	8.0	5.0	0.85
.....	200.0	20 7	11.4	7 6	5 1	3.2	0 54
.....	100.0	14.7	8 0	5.4	3.6	2.2	0 38
.....	50.0	10.4	5 7	3.8	2.5	1.6	0 27
.....	20 0	6 6	3 6	2.4	1.6	1.0	0 17
.....	10.0	4.6	2 5	1.7	1.1	0.71	0 12
.....	5.0	3.3	1.8	1.2	0.80	0.50	.....
.....	2.0	2.1	1 1	0.76	0.51	0.32	.....
.....	1.0	1.5	0 80	0.54	0.36	0 22	.....
.....	0.5	1.0	0.57	0.38	0.25	0 16	.....
90 0	0.2	0.66	0 36	0.24	0.16	0 10	.....
45 0	0.1	0 46	0 25	0 17	0.11	.....	.....
22.5	0.05	0.33	0.18	0.12	.....	.....	.....
9 0	0.02	0.21	0.11	.....	.....	.....	.....
4 5	0.01	0.15	.....	.....	.....	.....	.....
2.25	0.005	0.10	.....	.....	.....	.....	.....

## SIZE-WEIGHT RATIO IN SAMPLING<sup>1</sup>

Diameter of largest particle, inches	Minimum weight of sample, pounds Colorado practice
0.04	0 0625
0.08	0.50
0.16	4 00
0.32	32 00
0.64	256 00
1.25	2,048.00
2.50	16,348.00

<sup>1</sup> E. A. SMITH, "Sampling and Assay of the Precious Metals."

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## SMALLEST PERMISSIBLE WEIGHT FOR SAMPLES OF A GIVEN SIZE<sup>1</sup>

Size, inches cube or mesh	Weight of sample, lb.	Ratio of weight of largest cube to weight of sample	Effect on value created by one cube assaying \$100,000 per ton, of sp. gr. 5
2	10,000	1: 7,000	\$14.42
1½	5,000	1: 8,300	12.17
1	2,000	1: 11,000	9.00
¾	1,000	1: 13,000	7.50
½	400	1: 18,000	5.62
⅜	300	1: 31,000	3.17
¼	200	1: 71,000	1.40
⅓	100	1: 83,000	1.20
⅛	75	1: 220,000	0.44
6 mesh	50	1: 430,000	0.23
10 mesh	25	1: 930,000	0.107
18 mesh	10	1:1,900,000	0.051
30 mesh	4	1:4,200,000	0.023
50 mesh	1	1:5,500,000	0.018

<sup>1</sup> R. H. RICHARDS, "Ore Dressing," Vol. III.

## SCHEME FOR SAMPLING RICH ORES WITH VEZIN SAMPLERS<sup>1</sup>

	Inches	Sample, per cent.	Lb. in 100 tons
Maximum size of cubes.	1.00	20.0000	40,000
Maximum size of cubes.	0.25	1.25	2,500
8 mesh.....	0.0625	0.0785	157
30 mesh.....	0.0171	0.005	10

<sup>1</sup> R. H. RICHARDS, "Ore Dressing," Vol. III.

### Coal Sampling<sup>1</sup>

SIZE OF SLATE CONTAINED IN COAL, AND SIZE OF ORIGINAL SAMPLE REQUIRED TO INSURE THE ERROR OF SAMPLING BEING LESS THAN 1 PER CENT.

Size of slate, inches	Weight of largest piece of slate, lb.	Original sample should weigh, lb.
4	6.7	39,000
3	2.5	12,500
2	0.75	3,800
1½	0.38	1,900
1¼	0.24	1,200
1	0.12	600
¾	0.046	230
½	0.018	90

SIZE TO WHICH SLATE AND COAL SHOULD BE BROKEN BEFORE QUARTERING SAMPLES OF VARIOUS WEIGHTS

Weight of sample to be divided, lb.	Should be broken to, inches	Weight of sample to be divided, lb.	Should be broken to, inches
7500	2	40	2 mesh
3800	1½	5	4 mesh
1200	1	½	8 mesh
460	¾	¼	10 mesh
180	½	...	...

### Coke Sampling<sup>2</sup>

A point that is of utmost importance in the sampling of coke for blast-furnace use is the ash determination, since every pound of ash in a ton of coke means more expensive fluxing, increased cost of smelting, useless cinder and less furnace capacity available for the production of metal. For this reason differences of opinion as to the ash content of coke for blast-furnace use often cause bitter controversies.

In an investigation of this subject several years ago, I was surprised to find how much of the apparent ash content of coke was due to foreign material introduced in the process of grinding the sample. For instance, the analysis of a sample reported as containing 17 per cent. of ash showed that one-seventeenth of this ash, or 1 per cent. of the weight of the sample, was iron

<sup>1</sup> *Journ. Ind. and Eng. Chem.*, p. 161, 1909.

<sup>2</sup> Excerpts from an original article in *Coal Age*, July 24, 1915.

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abraded from a BRAUN pulverizer, while the ordinary cast-iron bucking-board and muller much used in grinding samples to be tested introduces iron into the sample to the extent of from  $\frac{1}{2}$  to 3 per cent.

Whether the grinding be done by machinery or by hand, this introduction of foreign matter in grinding can be cut down greatly by the use of manganese- or chrome-steel grinding plates.

It is impossible to determine the amount of this contamination with a magnet, for the reason that too much coke dust will adhere to the iron filings. It is necessary to treat the sample with a neutral copper-sulphate solution, agitate thoroughly, filter and wash the residue with hot water until entirely free from soluble copper salts. This residue is now dried and ignited and the ash tested for copper or the coke treated directly with nitric acid to dissolve the copper. The weight of copper precipitated by the iron in this process is then calculated from the ratio of their respective atomic weights.

This method will not answer for the determination of any foreign material introduced by pebble mills, but is very effectual where the grinding surfaces are of iron. It may be objected that the original ash of the coke may have contained some iron which has been reduced to the metallic state by the red-hot carbon of the coke during the coking process. In answer to this argument, any iron in the coke is probably present as ferrous oxide and combined with silica to form ferrous silicate ( $\text{FeSiO}_3$ ). But in any event the objection is not valid, because if the coke sample is crushed in a silica-pebble mill or in an agate mortar, the iron in the coke does not react with neutral copper-sulphate solution.

### LIMIT BEYOND WHICH SAMPLES SHOULD NOT BE DIVIDED WHEN CRUSHED TO DIFFERENT SIZES IN LABORATORY

Size of coal mesh	Should not be divided to less than, grams
2	8300
4	1100
8	120
10	55
20	3
	} Should be pulverized to at least 60 mesh.

## METALLOGRAPHY<sup>1</sup>

Metallography deals with the physical state and the proximate constituents of a metal or an alloy. It has to do with the physical grouping, distribution of constituents, and relative dimensions of the substances as revealed by microscopic exami-

<sup>1</sup> Courtesy, The Engineering Foundation.



nation. It may be characterized as a study of the anatomy of metals.

*Steel* is an alloy the essential constituents of which are iron and carbon, the latter being the controlling element. Carbon exists in steel as a carbide of iron,  $\text{Fe}_3\text{C}$ , to which the name cementite is applied. The free iron, or *ferrite*, together with the *cementite*, has the power of forming a conglomerate called *pearlite*, a very intimate mechanical mixture composed of about 7 parts of ferrite to 1 part of cementite. If molten iron be cooled, there is formed first a solution of carbon in molten iron, then as the metal solidifies the carbon exists as cementite in solid solution in the iron. This solid solution is called *austenite*, and it crystallizes into imperfect crystals or grains. With further cooling the steel passes through a *critical*, or transformation, range of temperature (extreme range about 1650 to 1250°F.), and the two constituents of the metal pass successively through several transition stages, namely: *martensite*, in which long needle-like crystals are formed, giving a very hard and brittle substance; *troostite*, in which dark colored masses resembling sorbite (see below) are surrounded by a groundwork of martensite, the troostitic state yielding a substance hard but tougher than the martensitic; *sorbite*, in which cementite and ferrite are in a state resembling an emulsion, yielding a substance fairly hard and very tough; and *pearlite*, in which ferrite and cementite exist, usually in stratified layers or bands. If the steel has a carbon content of about 0.90 per cent., all the grains will be pearlite; if the carbon content is lower than 0.90 per cent., there will be grains of pearlite and grains of ferrite; if the carbon content is greater than about 0.90 per cent., there will be grains of pearlite and grains of cementite.

The presence of carbon or of other alloying elements retards the process of transition. By varying the rate of quenching steel the transition process may in general be halted at any desired stage, and the resulting cooled steel may be given any desired characteristic structure.

Heat treatment of steel is the proper control of heating and cooling so as to produce the desired structure (pearlitic, ~~sorbitic~~, etc.) and includes:

**Annealing** is a very slow cooling from above the critical range, which gives a large-grained, soft, pearlitic structure.

**Normalizing**.—Cooling from above the critical range in still air, giving a fine-grained pearlitic structure.

**Oil Quenching**.—Cooling from above the critical range by cooling in oil at room temperature, yielding steels of sorbitic or troostitic structure, depending on the carbon content. (Certain alloy steels yield a martensitic or even an austenitic structure with oil quenching.)

**Water Quenching**.—Cooling from above the critical range in water of room temperature.

**Drawing**.—Which consists in reheating quenched steel to a temperature slightly below the critical range and then cooling. This process tends to bring martensitic, troostitic, or sorbitic

steel towards the pearlitic state, and, by varying the temperature of drawing, it is possible to control the state of the steel with a good degree of precision.

Other liquids are sometimes used for quenching steel; such as molten lead, molten barium chloride, ice water, and brine.

Alloying elements, including carbon, retard the transition so that high-carbon steels and alloy steels are more susceptible to heat treatment than are low-carbon steels.

### Location of Test-Pieces

The location of the test-piece for microscopic examination is of prime importance. In the case of a casting of steel or cast iron, the section ought to be cut perpendicular to the surface so as to show the variation of structure from the outside to the interior. In the case of forged and rolled metal both cross and longitudinal sections should be examined, their location being determined by the nature of the forging, etc. For crankshafts definite locations are given with reference to the tensile test specimens. For guns, tangential specimens are required and for microstructure these should be cut parallel to the axis, etc. No one specimen is of necessity representative. The usual method of taking a cross-section from rods and bars, while showing segregation of the constituents, fails to reveal the usual lamination, for which a longitudinal section is necessary.

In defective material, the sample should be cut adjacent to the fracture or defect. When necessary the fracture can be protected during grinding and polishing by coating it with a heavy deposit of electrolytic copper, molten lead-tin solder or a mixture of litharge and glycerine. For hardened steel and other material likely to be tempered, fusible metals such as Rose's or Wood's alloys may be used.

### Method of Polishing

The method used for polishing specimens will depend primarily on the material to be examined and on the polishing equipment. In general, samples should not be over 1-in. square and their thickness should be less than the smallest dimension of the polished surface; otherwise there is a tendency to round off the edges.

The softer material can be cut with a saw, while harder metal may be cut with an emery disk or broken off with a hammer. A flat surface is at first obtained either by rubbing on a file held in a vise or by grinding on an emery wheel. In both cases it is necessary to avoid tearing the surface of the metal or causing it to flow. Perfectly smooth surfaces can be obtained by commercial surface-grinding machines.

Having obtained a flat surface in this way, the sample is next rubbed down on a series of emery papers, usually starting

with No. 00 Commercial followed\* by Nos. 0 and 00 French Emery. (Of course, other similar papers of domestic manufacture are also available and suitable for this purpose.) These papers may conveniently be mounted on revolving disks. Rubbing on one paper is stopped as soon as the scratches from the last operation have been taken out. From the No. 00 French Emery the specimen may be taken to a revolving disk covered with broadcloth, preferably running in a horizontal position at such a speed that the polishing powders are not unnecessarily thrown off. For ordinary work, two such disks will be sufficient, the first armed with well-washed carborundum, 65 or a similar grade, while the second may be armed with well-washed alumina. This is cleaner and better than rouge.

To obtain a fine polish it is a mistake to try to save time by hurrying through the papers because if this is done when the specimen is etched innumerable fine lines will be revealed in the ferrite. In some cases the appearance of the ferrite is actually blurred because the metal distorted in the grinding and by the coarse grades of emery has not been subsequently removed. Under no conditions should buffing be tried, because this causes an actual flow of the metal.

For material of small size, such as sheet and wire, numerous methods of mounting have been devised. For wire, various mounting media such as wax, a mixture of litharge and glycerine, fusible metals and the like can be used in a small brass container. For sheet metal, a pack can be built up of pieces of the sample with alternate layers of red fiber board, bakelite or other resistant material, the whole held together by two brass end pieces and two screws.

## **ETCHING REAGENTS AND THEIR APPLICATION<sup>1</sup>**

### **Etching Reagents for Iron and Steel**

**Copper-Ammonium Chloride.**—Usually consists of a 10 per cent. solution of the salt in water, and is suitable for ~~weight~~ light iron and mild steel. The specimen is immersed in the solution for about 1 minute, then washed, and the copper deposit which is readily detached, wiped off under running water. This reagent is used for deep etching effects, and also to darken parts rich in phosphorus.

**Copper Chloride.**—Dilute acidulated copper chloride in alcohol is used by STREAD to detect phosphorus in steels. The reagent is made up as follows:

Copper chloride.....	10 grams.
Magnesium chloride.....	80 grams.
Hydrochloric acid.....	20 cc.

The salts are dissolved in the least possible quantity of water, and the solution made up to 1000 cc. with alcohol. The purer

<sup>1</sup> O. F. HUDSON, "Iron and Steel Institute," March, 1915.

portions of the steel become coated with copper before the phosphoric portions.

**Hydrochloric Acid.**—A dilute solution (1 per cent.) in ethyl alcohol is generally used. HOYT writes that a solution of 1 cc. hydrochloric acid (sp. gr. 1.19) in 100 cc. absolute alcohol "is recommended for all the iron-carbon alloys whether in a hardened or annealed state," while the action can be accelerated (for special steels) by the addition of a few cubic centimeters of a 5 per cent. solution of picric acid in alcohol.

**Iodine.**—The ordinary tincture should be used. A simple solution in absolute alcohol is not so suitable. The specimen may be immersed in the solution, or a drop or two placed on the surface to be etched, and allowed to remain until decolorized.

**Nitric Acid.**—Until the introduction of picric acid, a dilute solution of nitric acid was the principal etching agent for iron and steel, and it is still often used. Solutions (up to about 5 per cent.) in water, or, preferably, alcohol, are generally used. When alcohol is the solvent, absolute alcohol should be used for washing the specimen, and not water. LANTSBERRY (c), who always uses nitric acid for steels, points out that the success of the method depends on thoroughly washing the specimen with alcohol and drying at once, and that the surface should never be moistened with water.

SAUVEUR (c) writes that for all grades of steel, wrought iron, and pig iron, regardless of treatment, he uses solutions of concentrated nitric acid in absolute alcohol, in proportions varying between 1 and 10 per cent. of acid, according to requirements. He prefers it to picric acid. The samples are washed in absolute alcohol and dried by means of an air-blast. For manganese steel he uses 10 per cent. nitric acid in absolute alcohol, leaving the specimen in the bath until it is covered with a black deposit. It is then washed in alcohol, without any attempt at removing the deposit by rubbing.

HOWE (c) uses a solution of 2 per cent. of concentrated nitric acid in water for hardened steels, manganese steels, etc., and also occasionally to develop grain boundaries quickly in low-carbon material, although he notes that it roughens up the ferrite much more than picric acid. He recommends a preliminary treatment for the removal of grease, using "alcohol, hydrochloric acid in alcohol, or, best, picric acid in alcohol."

A 4 per cent. solution of nitric acid in iso-amyl alcohol (as suggested by KOURBATOFF) is also used, and gives a slow and delicate etching.

**Picric Acid.**—This reagent, introduced by ISCHEWSKY, is the one most commonly used, generally as a saturated or nearly saturated solution in alcohol. The specimen is immersed for times varying with the kind of steel and the effect desired, from a few seconds for light etching of ordinary rolled or annealed steels and cast irons, to several minutes for hardened steels and wrought irons. Picric acid is sometimes used in conjunction with nitric acid. Thus DESCH (c) recommends for all ordinary (unhardened) steels alcoholic picric acid to which a few drops of

nitric acid have been added. A solution of picric acid in amyl alcohol is also used for a slow etching. L. ARCHBUTT (c) also finds it "an advantage to add a small quantity of nitric acid, which gives greater certainty of etching, especially in cold weather." The solution he uses contains 80 vols. of picric acid in alcohol and 20 vols. of 2 per cent. nitric acid in alcohol.

ROSENHAIN's and HAUGHTON's Reagent consists of:

Ferric chloride.....	30 grams
Hydrochloric acid (conc.).....	100 cc.
Cupric chloride.....	10 grams
Stannous chloride.....	0.5 grams
Water.....	1000 cc.

It is used for determination of the distribution of phosphorus in steel, the purer portions of the steel being stained by deposition of copper, leaving the phosphorus-rich portions white.

Of the numerous other reagents some are used for special purposes, such as sodium picrate, for the detection of cementite; while others are more or less complicated solutions, such as KOURBATOFF's reagent.

#### Kourbatoff's Solutions for Hardened Steel<sup>1</sup>

**Solution A.**—4 cc.  $\text{HNO}_3$  in 96 cc. amyl alcohol, acting 5 min., will color troostite brown, austenite yellow, martensite white.

**Solution B** differentiates the various constituents. It consists of 1 volume of saturated solution of ortho-nitrophenol in alcohol, and 2 volumes of 20 per cent.  $\text{HCl}$  in amyl alcohol.

**Solution C.**—Mix just before using a solution of 4 per cent.  $\text{HNO}_3$  in acetic anhydride with three times the volume of a mixture of equal parts of amyl, ethyl, and methyl alcohols. It colors troostite and troostite-sorbite.

**Solution D.**—1 volume of 4 per cent.  $\text{HNO}_3$  in ethyl alcohol plus 3 volumes saturated solution of nitrophenol in ethyl alcohol; immersion of 10 min. colors troostite and martensite needles.

**Solution E for Troostite.**—2 parts methyl alcohol, 2 parts ethyl alcohol, 2 parts amyl alcohol, 1 part butyl alcohol, 3 parts of 4 per cent.  $\text{HNO}_3$  in acetic anhydride.

**Solution F.**—4 per cent.  $\text{HNO}_3$  in methyl alcohol to which  $\frac{1}{10}$  of its volume of 4 per cent. picric acid in ethyl alcohol is added. Colors austenite, martensite and troostite differently.

**Solution G.**—1 volume of  $\text{HNO}_3$  in alcohol and 3 volumes of saturated solution of nitriline. Colors troostite, troostite-sorbite and martensite needles.

**Benedicks' Solution.**—5 per cent. meta-nitrobenzol sulphonic acid in alcohol. Darkens martensite more than austenite after immersion of 15 sec.

<sup>1</sup> From the *A. S. T. M. Symposium*, 1921.

## Solutions for Carbides

**Kourbatoff.**—2 grams picric acid, 25 grams NaOH, 75 cc. water. Cementite will be colored after boiling 5 to 10 min. Ferrite and tungsten carbide (WC) are unattacked. Various other compounds, such as  $\text{Fe}_3\text{W}$  and  $\text{Fe}_3\text{W}_2\text{C}$ , are colored.

**Matwieff.**—Boil specimen 20 min. in a neutral solution of sodium picrate, and wash thoroughly. Iron phosphide is attacked, but cementite is not.

**Yatsevitch.**—Tungsten carbide in high-speed steel is darkened by immersing 10 to 12 min. in a fresh mixture of 10 cc. commercial  $\text{H}_2\text{O}_2$  in 20 cc. of a 10 per cent. water solution of NaOH.

**Hilpert and Colver-Glauert.**—Non-pearlitic steels and pig iron may be etched for from 7 sec. to 1 min. in 3 or 4 cc. saturated aqueous solution of  $\text{SO}_2$  in 100 cc. alcohol or water.

**Murakami.**—Carbide and tungstide in high-speed and tungsten steels may be distinguished by a hot solution of 10 gram. potassium ferricyanide, 10 grams KOH and 100 cc. water.

## Electrolytic Etching

This method is of great value in special cases. Generally a solution of a neutral salt is used as the electrolyte; the specimen is made the anode and a piece of platinum foil the cathode. A feeble current of a small fraction of an ampere is used. DESCH (c) finds that etched figures in brasses, etc., are most perfectly developed by electrolytic etching, using a 5 per cent. sodium-chloride solution and a platinum cathode with two dry cells. Other electrolytes used are ammonium nitrate, sodium thio-sulphate (used by LE CHATELIER for copper-tin alloys), ammonia, and sometimes very dilute acid solutions.

For Monel metal, L. ARCHBUT (c) "obtained very good results by electrolytic etching in a solution containing 45 cc. dilute sulphuric acid (1:3) and 5 cc. hydrogen peroxide solution, using a current of 0.1 amp. and 0.5 volt, etching for about 50 seconds. A slight staining of the specimen was subsequently removed by light rubbing with a dilute solution of bromine in hydrochloric acid." Constantan was etched in a similar way "but stains were removed by using a mixture of dilute sulphuric acid and hydrogen peroxide and rubbing with the finger." ROSENHAIN (c) has also found that electrolytic etching is useful for nickel-copper alloys.

**Polish Attack.**—Used with much success by OSMOND and it is one which, if not always applicable, is not adopted so widely as it should be. The objections which appear to be urged against the method are (a) the difficulty of getting uniformly good results, and (b) the danger of obscuring the structure by the flowing action of polishing. Neither of these objections need, however, be serious; the former is overcome by experience, while the latter is probably largely imaginary, unless altogether unnecessary pressure is used. The procedure which has been found suitable for copper and its alloys has already been de-

scribed in dealing with ammonia as an etching agent. For steels OSMOND used a very gentle etching reagent, such as a 2 per cent. solution of ammonium nitrate with precipitated calcium sulphate in parchment, but this method is not now so often used. The author, however, for iron and steel, makes use of parchment thoroughly soaked in water on which a paste of precipitated calcium sulphate is spread. The specimen is then alternately lightly etched with picric acid, and rubbed gently for a few seconds on the parchment. Frequently also it is found to be an advantage to etch the specimen lightly, then polish very gently with alumina and re-etch, repeating if necessary.

GWYER (c) finds that polish attack is sometimes very effective for light aluminum alloys, "for example, in bringing out the structure of the iron-aluminum eutectic. For this washed and ignited magnesia is required, the polishing being done on parchment kept moistened with very dilute caustic soda solution."

GULLIVER (c) notes that sometimes a good polish attack may be obtained with water alone, although not if the pad is new. He found, for example, that polish attack with water alone was defective in the case of bismuth-tin alloys.

**Heat-tinting.**—Although not perhaps, strictly speaking, an etching process, heat-tinting is a valuable and widely used method of revealing the structure of alloys, and especially for the detection of small differences in concentration of solid solutions. It consists in heating the specimen until a thin film of oxide is formed on the surface, differences in composition giving rise to variations in thickness, and hence variations in color of the film. STEAD used it with great advantage in studying phosphoric cast irons and alloys of iron and phosphorus, and showed that by its use phosphide and carbide of iron could readily be distinguished, while HEYCOCK and NEVILLE proved its value in their work on the copper-tin alloys. STEAD has also applied the method to the determination of the distribution of phosphorus in steel. In a paper on "Metallographic Methods for the Detection of Phosphorus in Steel," read before the Cleveland Society of Engineers in December, 1914, STEAD gives details of the heat-tinting method suitable for this purpose: The specimen is floated on a bath of molten tin at a temperature of about 300°C., and allowed to remain until the whole surface has a reddish-brown color. On examining the specimen, the portions richest in phosphorus will be detected by their blue color, since the parts which are richer in phosphorus than the surrounding metal become colored more quickly. The preliminary treatment of the specimen before it is raised to the tinting temperature is important. Washing with a 1 per cent. solution of picric acid in alcohol is recommended, and the surface should always be "cleaned by rubbing with a clean piece of linen or cotton. The specimen is heated to about 150°C., and then rubbed with a clean piece of chamois leather while still hot." It is then immediately raised to the tinting temperature.

Instead of heating in air, and obtaining a colored oxide film, STEAD has shown that other atmospheres may be used,

such as sulphuretted hydrogen or bromine. The use of an atmosphere containing bromine for the examination of MUNTZ metal has been described recently by STEAD.

Heat-tinting appears to require considerable experience in order to obtain consistent results, and the author, among others, cannot rely upon it to be uniformly successful. The following is a summary of the principal reagents for particular metals and alloys.

### Etching Reagents Suitable for Particular Metals and Alloys Solutions for Alloy Steels

Austenitic nickel steels may be etched in 5 grams  $\text{Fe}_2\text{Cl}_6$ , 50 cc.  $\text{HCl}$  and 100 cc.  $\text{H}_2\text{O}$ .

Stellite and high-chromium steels may be etched with a very weak electric current in a 0.5 per cent.  $\text{NaOH}$  solution.

On 110-volt circuit use two 4-cp. lamps in series, connected with two-wire terminal (platinum wire preferable). Flood surface of specimen with solution, and make contact with one wire at side and dip the other in the solution, moving it around to obtain uniform etch.

### Methods for Identification of Non-metallic Inclusions

STEAD<sup>1</sup> uses 30 per cent.  $\text{H}_2\text{SO}_4$ . Bubbles arise from sulphides but none from silicates or oxides.

LAW<sup>2</sup> uses an acid solution of lead or cadmium salt in gelatine. The sulphides form deep brown or yellow stain of cadmium or lead sulphide. Oxides or silicates unaffected. He also recommends as an electrical etching solution consisting of distilled water with 0.002 per cent ammonium chloride or caustic potash used boiling. After a few minutes wash and dry with alcohol. Results:  $\text{MnS}$  unaltered.  $\text{FeO}$  and  $\text{FeO}_2\text{MnO}_2$  is reduced, but  $\text{MnO}$  unaffected.

### MEANS FOR THE IDENTIFICATION OF NON-METALLIC INCLUSIONS

As polished	
$\text{FeS}$ . . . . .	Brownish yellow
$\text{MnS}$ . . . . .	Slate blue, smooth
$\text{FeS}_2\text{MnS}_2$ . . . . .	Slate blue to brown, may show duplex structure
$\text{FeO}$ . . . . .	Slate blue, rough, a little darker than $\text{MnS}$
$\text{MnO}$ . . . . .	Similar
$\text{Mn-silicate}$ . . . . .	Greenish tinge, smooth and greasy
$\text{Fe-silicate}$ . . . . .	Black and greasy
$\text{Al}_2\text{O}_3$ . . . . .	Tiny hard rounded grains, never elongated by rolling, etc.
Sand grains . . . . .	Angular form, convex side, greasy appearance standing in high relief
Titanium nitride & cyanonitride . . . . .	Pink or yellow cubic crystals

<sup>1</sup> STEAD, *Iron and Steel*, Vol. 9, p. 105.

<sup>2</sup> LAW, *Journ. Iron and Steel Inst.*, Vol. 2, p. 94, 1907.



Matwieff<sup>1</sup> uses hydrogen or steam<sup>2</sup> at 600 deg. C., or organic acids to distinguish oxides, silicates and sulphides as follows:

	Oxides	Silicates	Sulphides
Hot hydrogen.....	Reduced	Unaffected	Unaffected
Hot steam.....	Attacked	Unaffected	Unaffected
Organic acids.....	Unaffected	Unaffected	Attacked
2 per cent. HF in absolute alcohol <sup>1</sup> .	Unaffected	Darkens	Darkens

<sup>1</sup> Regent due to McCANCE. Action occurs in 3 sec. Another recommended solution contains 8 cc. HF, 42 cc. water and 50 cc. alcohol.

Iron oxide may be distinguished from manganese oxide by repolishing the sample reduced by hot hydrogen, and etching with dilute solution of  $\text{FeCl}_3$  in alcohol. If colored feebly, the inclusion is  $\text{FeO}$ ; if colored deeply, it is  $\text{MnO}$  with some  $\text{FeO}$ ;  $\text{MnO}$  alone is not reduced. Iron sulphide is colored by tartaric acid, while  $\text{MnS}$  is very feebly colored.

### Sulphides

ROHL<sup>2</sup> recommends a 1 per cent solution of acetic, citric, oxalic or picric acid in water, noting that picric acid gives the most uniform results on sulphides.  $\text{FeS}$  is always readily blackened in 1 min.;  $\text{MnS}$  is slightly blackened in 45 sec. Sulphides also give a dark brown color after a triple etching (a) 4 g. picric acid in 100 cc. amyl alcohol, (b) 4 cc.  $\text{HNO}_3$  in 100 cc. amyl alcohol, (c) concentrated hot  $\text{NaOH}$ . A 2 per cent sodium acetate will give  $\text{FeS}$  a brownish tint in 1 min., whereas  $\text{MnS}$  is colored but very lightly.

Reduction tests for sulphides: Sulphides are covered by mercury after immersion in  $\text{HgCl}_2$  solution. If the sample is lightly repolished,  $\text{FeS}$  will be found corroded but  $\text{MnS}$  not. A 3 per cent. boiling solution of  $\text{AgNO}_3$  will color  $\text{FeS}$  a uniform violet blue and  $\text{MnS}$  a slightly darkened dove gray. On repolishing,  $\text{FeS}$  appears a reddish violet, and  $\text{MnS}$  a blue gray.

CAMPBELL's method of distinction: A short preliminary etching with 1 per cent. picric acid in ethyl alcohol, followed by tempering to dark yellow, changes  $\text{FeS}$  into a beautiful dark blue to reddish violet, and  $\text{MnS}$  into dull gray to bright white.

Whitely recommends that 5 grams gelatine be soaked 1 hr. in 20 cc. water and 15 cc. gelatine added. Heat till clear, add 0.05 grams tartar emetic in 1 cc.  $\text{H}_2\text{O}$ , filter, and add 1 cc. dilute  $\text{H}_2\text{SO}_4$ . Apply warm. Yellow ring forms around sulphides.

McCANCE<sup>3</sup> replaces tartar emetic by 0.1 gram  $\text{AgNO}_3$ , when a black stain indicates sulphide.

COMSTOCK<sup>4</sup> uses boiling alkaline picrate of soda.  $\text{MnS}$  is blackened and roughened, while silicates and oxides are unaffected.

<sup>1</sup> MATWIEFF, *Rev. Metall.*, Vol. 7, p. 447.

<sup>2</sup> ROHL, *Journ., Iron and Steel Inst. Carnegie Memoir*, Vol. 4, p. 28, 1912.

<sup>3</sup> McCANCE, *Journ., Iron and Steel Inst.*, pp. 1-239, 1918.

<sup>4</sup> COMSTOCK, *Trans., A.I.M.E.*, Vol. 56, p. 553, 1916.

**KARL DAEVES**, in *Stahl und Eisen*, Sept. 8, 1921, p. 1262, emphasizes the advantages of potassium ferricyanide as an etching reagent for Cr and W steels, first proposed by K. HONDA and T. MURAKAMI. According to the Japanese authors, there are three carbides in Cr steels—namely,  $\alpha$ -carbide ( $\text{Fe}_3\text{C}$ ),  $\beta$ -carbide ( $\text{Fe}_3\text{C}$ ),  $\gamma$ -carbide ( $\text{Fe}_3\text{C}$ ). A mixture of 10 grams potassium ferricyanide and 10 grams KOH in 100 cc. water acts as follows:  $\alpha$ -carbide is attacked even in the cold, giving a brown to blue coloration;  $\beta$ -carbide is attacked only when hot, and  $\gamma$ -carbide is not attacked. High-speed with over 12 per cent. tungsten contains the compound  $\text{Fe}_2\text{W}$ , which is easily attacked by the cold reagent, giving a brown to blue coloration.

This reagent is not satisfactory for pig iron, carbon and Ni:Cr steels.

The following list gives the principal reagents which have been found especially suitable for different metals and alloys:

**Aluminum and Light Aluminum Alloys.**—Caustic soda, hydrochloric acid, hydrofluoric acid (1 part fuming HF to 10 or 20 parts of water, clear after treatment by a few second's immersion in  $\text{HNO}_3$ ). Also VILLELA's reagent, 2 parts glycerol, 2 parts 30 per cent. HF and 1 part  $\text{HNO}_3$ .

**Brasses.**—Ammonia, ammonium persulphate, copper-ammonium chloride, electrolytic etching, ferric chloride (slightly acidulated with HCl), chromic acid (saturated or nearly saturated solution), nitric acid (strong acid, followed by water), Tinfoef's reagent (94 grams  $\text{HNO}_3$  and 6 grams  $\text{Cr}_2\text{O}_3$ , a few drops are used in 50 cc. of water).

**Bronzes.**—Ammonia, ammonium persulphate, ferric chloride.

**Copper.**—Ammonia (sp. gr. 0.88, diluted 1:1 with water), ammonium persulphate (10 per cent. aqueous solution), bromine (followed by a wash with ammonia), copper-ammonium chloride (5 grams of copper-ammonium chloride in 100 cc. of water, add ammonia until precipitate just dissolves).

**Copper-aluminum Alloys (Aluminum Bronzes).**—Ammonium persulphate, ferric chloride, copper-ammonium chloride, nitric acid.

**German Silver.**—Ammonium persulphate, ferric chloride.

**Gold and Rich Gold Alloys, Platinum and Its Alloys.**—*Aqua regia* (dilute, 1 part  $\text{HNO}_3$ , 5 parts HCl, 6 parts distilled water, used at  $15^\circ\text{C}$ .).

**Iron Silicon Alloys.**—Villela's reagent, 2 parts glycerol, 2 parts 30 per cent. HF, and 1 part  $\text{HNO}_3$ .

**Lead, Tin and Their Alloys (White Metal, etc.).**—Chromic acid in nitric acid, ferric chloride, hydrochloric acid, nitric acid, silver nitrate (5 per cent. solution).

**Monel Metal.**—Ferric chloride, ammonium persulphate, (see also Nickél).

**Nickel, Nickel-copper Alloys.**—Electrolytic etching. See p. 408 or nitric acid either alone or 50 per cent.  $\text{HNO}_3$ , 40 per cent. glacial acetic acid and 10 per cent. water.

**Platinum.**—The usual reagent is *aqua regia*, but it fails if the percentage of Os, Tr, Rh or Ru is high. In such cases fusion with potassium bisulphate or potassium hydroxide with 10 per cent. of potassium nitrate is useful. Heat etching may also be used.

**Palladium and Its Alloys.**—A cold solution of *aqua regia* in alcohol or glycerin or boiling concentrate nitric acid.

**Sterling Silver.**—Alkaline cuprammonium chloride; ammonium persulphate; heating tinting, or better still, E. A. ANDERSON'S reagent:

<b>Solution A.</b> —Potassium dichromate.....	2 grams
Nitric acid (1:1)*.....	100 cc.
<b>Solution B.</b> —Chromic acid .....	20 grams
Sodium sulfate.....	1.5 grams
Water.....	100 cc.

Solution A is diluted to 20 volumes and an equal volume of Solution B is added. When properly mixed and applied with a camel's-hair brush, a red silver chromate should form; this remains granular and does not adhere to the surface of the specimen. If the chromate adheres, more Solution A should be added, and if no chromate forms, more of Solution B is needed.

**Tungsten Carbides, (Thoron, Diamonite, Elmarid, Walramite and Widia).**—Alkaline ferrieyanide attacks WC and not  $W_2C$ ; a mixture of concentrated nitric and hydrofluoric acids attacks  $W_2C$  and not WC.

**Zinc and Alloys Rich in Zinc.**—Caustic soda, iodine (1 part iodine, 3 parts KI, and 10 parts water), 1 per cent. iodine in alcohol; mixture of chromic and nitric acids.

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## GRAVIMETRIC FACTORS

	Give	Sought	Multiply by factor N
Aluminum, 26.96	$\text{Al}_2\text{O}_3$	Al	0.5290
	Al	$\text{Al}_2\text{O}_3$	1.8902
	$\text{AlPO}_4$	$\text{Al}_2\text{O}_3$	0.4103
	$\text{Al}_2\text{O}_3$	$\text{Al}_2(\text{SO}_4)_3$	3.3567
Antimony, 121.77	$\text{Sb}_2\text{O}_4$	Sb	0.7919
	$\text{Sb}_2\text{O}_4$	$\text{Sb}_2\text{O}_3$	0.9479
	$\text{Sb}_2\text{O}_4$	$\text{Sb}_2\text{O}_5$	1.0523
	$\text{Sb}_2\text{S}_3$	Sb	0.7168
	$\text{Sb}_2\text{S}_3$	$\text{Sb}_2\text{O}_3$	0.8581
	$\text{Sb}_2\text{S}_3$	$\text{Sb}_2\text{O}_5$	0.9523
	Sb	$\text{Sb}_2\text{O}_3$	1.1971
	Sb	$\text{Sb}_2\text{O}_5$	1.3285
	$\text{As}_2\text{S}_3$	As	0.6091
	$\text{As}_2\text{S}_3$	$\text{As}_2\text{O}_3$	0.8041
Arsenic, 74.96	$\text{As}_2\text{S}_3$	$\text{As}_2\text{O}_3$	0.9341
	$\text{As}_2\text{S}_3$	$\text{AsO}_4$	1.1291
	$\text{As}_2\text{S}_5$	As	0.4832
	$\text{Mg}_2\text{As}_2\text{O}_7$	As	0.4827
	$\text{Mg}_2\text{As}_2\text{O}_7$	$\text{As}_2\text{O}_3$	0.6373
	$\text{Mg}_2\text{As}_2\text{O}_7$	$\text{As}_2\text{O}_5$	0.7403
	$\text{Mg}_2\text{As}_2\text{O}_7$	$\text{AsO}_4$	0.8949
	$\text{Ag}_3\text{AsO}_4$	As	0.1620
	As	$\text{As}_2\text{O}_3$	1.3202
	As	$\text{As}_2\text{O}_5$	1.5336
	$\text{BaSO}_4$	Ba	0.5885
	$\text{BaSO}_4$	BaO	0.6568
	$\text{BaCrO}_4$	Ba	0.5422
Barium, 137.37	$\text{BaCrO}_4$	BaO	0.6053
	$\text{BaCO}_3$	Ba	0.6960
	$\text{BaCO}_3$	BaO	0.7771
	Ba	BaO	1.1165
	$\text{Bi}_2\text{O}_3$	Bi	0.8973
	$\text{BiOCl}$	Bi	0.8024
	$\text{BiOCl}$	$\text{Bi}_2\text{O}_3$	0.8946
	$\text{Bi}_2\text{S}_3$	Bi	0.8129
Bismuth, 209.0	$\text{Bi}_2\text{S}_3$	$\text{Bi}_2\text{O}_3$	0.9062
	Bi	$\text{Bi}_2\text{O}_3$	1.1148
	$\text{B}_2\text{O}_3$	B	0.3107
	B	$\text{B}_2\text{O}_3$	3.2181
	AgBr	Br	0.4255
Bromine, 79.916	AgBr	HBr	0.4309
	Br - Cl	Br	1.7969
	Br - Cl	AgBr	4.2202
	Br	$\text{O}^{1/2}$	0.1001

GRAVIMETRIC FACTORS. *Continued*

	Given	Sought	Multiply by factor <i>N</i>
Cadmium, 112.41. .	CdO	Cd	0.8754
	CdS	Cd	0.7780
	CdS	CdO	0.8888
	Cd	CdO	1.1424
Caesium, 132.81	Cs <sub>2</sub> SO <sub>4</sub>	Cs	0.7344
	Cs <sub>2</sub> PtCl <sub>6</sub>	Cs	0.3943
	Cs	Cs <sub>2</sub> O	1.0623
Calcium, 40.07.....	CaO	Ca	0.7146
	CaO	CaCO <sub>3</sub>	1.7847
	CaSO <sub>4</sub>	Ca	0.2943
	CaSO <sub>4</sub>	CaO	0.4119
	CaCO <sub>3</sub>	Ca	0.4005
	CaCO <sub>3</sub>	CaO	0.5603
	Ca	CaO	1.3993
	Ca	CaC <sub>2</sub> O <sub>4</sub>	2.4971
	CaO	CaC <sub>2</sub> O <sub>4</sub>	2.2841
	CaC <sub>2</sub> O <sub>4</sub>	CO <sub>2</sub>	0.3436
	CaCO <sub>3</sub>	CO <sub>2</sub>	0.4397
	CO <sub>2</sub>	C	0.2727
Carbon, 12.00.....	C	CO <sub>2</sub>	3.6667
	CO <sub>2</sub>	CO <sub>3</sub>	1.3636
	AgCl	Cl	0.2474
	AgCl	HCl	0.2544
	Ag	Cl	0.3287
	Cl	O $\frac{1}{2}$	0.2256
	AgCl	O $\frac{1}{2}$	0.05581
	Cr <sub>2</sub> O <sub>3</sub>	Cr	0.6842
Chromium, 52.01.	Cr <sub>2</sub> O <sub>3</sub>	CrO <sub>3</sub>	1.3158
	PbCrO <sub>4</sub>	Cr	0.1609
	PbCrO <sub>4</sub>	Cr <sub>2</sub> O <sub>3</sub>	0.2351
	PbCrO <sub>4</sub>	CrO <sub>3</sub>	0.7664
	Cr	Cr <sub>2</sub> O <sub>3</sub>	1.4615
	Cr	CrO <sub>3</sub>	1.9230
	CoSO <sub>4</sub>	Co	0.3804
	Co <sub>3</sub> O <sub>4</sub>	Co	0.7343
Cobalt, 58.97	Co	CoO	1.2713
	Co(NO <sub>2</sub> ) <sub>3</sub> 3KNO <sub>2</sub>	Co	0.1304
	CuO	Cu	0.7989
	Cu	CuO	1.2517
Copper, 63.57.....	Cu <sub>2</sub> S	Cu	0.7986
	Cu <sub>2</sub> S	CuO	0.9996
	CuSCN	Cu	0.5226
	CuSCN	CuO	0.6541

GRAVIMETRIC FACTORS. *Continued*

	Given	Sought	Multiply by factor <i>N</i>
Cyanogen, 26.01....	AgCN	CN	0.19427
	Ag	CN	0.2411
Fluorine, 19.00.....	CaF <sub>2</sub>	F	0.4867
	SiF <sub>4</sub>	F	0.7303
Gold, 197.2 .....	Au	AuCl <sub>3</sub>	1.5395
Hydrogen, 1.008....	H <sub>2</sub> O	H	0.11190
Iodine, 126.932.....	AgI	I	0.54056
	PdI <sub>2</sub>	I	0.7041
	I - Cl	I	1.3877
	I - Cl	AgI	2.5673
Iron, 55.84.....	Fe <sub>2</sub> O <sub>3</sub>	Fe	0.6994
	Fe <sub>2</sub> O <sub>3</sub>	FeO	0.8998
	Fe <sub>2</sub> O <sub>3</sub>	Fe <sub>3</sub> O <sub>4</sub>	0.9666
	Fe <sub>2</sub> O <sub>3</sub>	FeS <sub>2</sub>	1.5028
	FeO	Fe	0.7773
	FeO	Fe <sub>2</sub> O <sub>3</sub>	1.1114
	FeS	Fe	0.6352
	Fe	FeO	1.2865
	Fe	Fe <sub>2</sub> O <sub>3</sub>	1.4298
Lead, 207.2... ..	PbSO <sub>4</sub>	Pb	0.6832
	PbSO <sub>4</sub>	PbO	0.7360
	PbSO <sub>4</sub>	PbO <sub>2</sub>	0.7887
	PbSO <sub>4</sub>	PbS	0.7890
	PbCrO <sub>4</sub>	Pb	0.6411
	PbCrO <sub>4</sub>	PbO	0.6906
	PbS	Pb	0.8660
	PbS	PbO	0.9328
	PbCl <sub>2</sub>	Pb	0.7450
	PbO	Pb	0.9283
	Pb	PbO	1.0772
Lithium, 6.939... ..	Li <sub>2</sub> SO <sub>4</sub>	Li	0.12623
	Li <sub>2</sub> SO <sub>4</sub>	Li <sub>2</sub> O	0.27176
	Li <sub>3</sub> PO <sub>4</sub>	Li	0.17970
	Li	Li <sub>2</sub> O	2.1529
	Li <sub>2</sub> CO <sub>3</sub>	Li	0.1879
	Li <sub>2</sub> CO <sub>3</sub>	Li <sub>2</sub> O	0.4044
Magnesium, 24.32..	Mg <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	Mg	0.2184
	Mg <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	MgO	0.3621
	Mg <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	MgCO <sub>3</sub>	0.7572
	MgSO <sub>4</sub>	Mg	0.20202
	MgSO <sub>4</sub>	MgO	0.33492
	MgO	Mg	0.6032
	MgO	MgCO <sub>3</sub>	2.0912
	Mg	MgO	1.6579

GRAVIMETRIC FACTORS. *Continued*

	Given	Sought *	Multiply by factor N
Manganese, 54.93...	Mn <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	Mn	0.3869
	Mn <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	MnO	0.4996
	Mn <sub>3</sub> O <sub>4</sub>	Mn	0.7203
	Mn <sub>3</sub> O <sub>4</sub>	MnO	0.9301
	MnS	Mn	0.6314
	MnS	MnO	0.8153
	MnSO <sub>4</sub>	Mn	0.3638
	MnSO <sub>4</sub>	MnO	0.4697
	MnO	MnO <sub>2</sub>	1.2256
	Mn	MnO	1.2913
	Mn	MnO <sub>2</sub>	1.5826
Mercury, 200.61.	HgS	Hg	0.8622
	HgS	HgO	0.9309
	HgCl	Hg	0.8498
	HgCl	HgO	0.9176
	Hg	HgO	1.0798
Molybdenum, 96.0...	MoO <sub>3</sub>	Mo	0.6667
	PbMoO <sub>4</sub>	MoO <sub>3</sub>	0.3922
Nickel, 58.69.....	NiSO <sub>4</sub>	Ni	0.3792
	NiO	Ni	0.7858
	Ni	NiO	1.2727
	NH <sub>4</sub> Cl	N	0.26186
Nitrogen, 14.01.....	NH <sub>4</sub> Cl	NH <sub>3</sub>	0.31838
	NH <sub>4</sub> Cl	NH <sub>4</sub>	0.33722
	(NH <sub>4</sub> ) <sub>2</sub> PtCl <sub>6</sub>	N	0.06309
	(NH <sub>4</sub> ) <sub>2</sub> PtCl <sub>6</sub>	NH <sub>3</sub>	0.07671
	(NH <sub>4</sub> ) <sub>2</sub> PtCl <sub>6</sub>	NH <sub>4</sub>	0.08125
	(NH <sub>4</sub> ) <sub>2</sub> PtCl <sub>6</sub>	NH <sub>4</sub> Cl	0.2411
	Pt	N	0.1435
	Pt	NH <sub>3</sub>	0.1745
	Pt	NH <sub>4</sub>	0.1948
	N	NH <sub>3</sub>	1.2158
	NH <sub>3</sub>	N	0.82247
	N	(NH <sub>4</sub> ) <sub>2</sub> O	1.8587
	N	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	4.7162
	N	N <sub>2</sub> O <sub>5</sub>	3.8579
	N	NO <sub>3</sub>	4.4261
	N	NO <sub>2</sub>	3.2841
	N	NO	2.1420
Phosphorus, 31.024.	Mg <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	P	0.2787
	Mg <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	P <sub>2</sub> O <sub>5</sub>	0.6379
	Mg <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	PO <sub>4</sub>	0.8534
	FePO <sub>4</sub>	P <sub>2</sub> O <sub>5</sub>	0.4708
	U <sub>2</sub> P <sub>2</sub> O <sub>11</sub>	P <sub>2</sub> O <sub>5</sub>	0.1989

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GRAVIMETRIC FACTORS. *Continued*

	Given	Sought	Multiply by factor <i>N</i>
Phosphorus, 31.024	P <sub>2</sub> O <sub>5</sub>	P	0.4369
	P	P <sub>2</sub> O <sub>5</sub>	2.2893
Platinum, 195.23...	(NH <sub>4</sub> ) <sub>2</sub> PtCl <sub>6</sub>	Pt	0.4396
	K <sub>2</sub> PtCl <sub>6</sub>	Pt	0.4015
Potassium, 39.095...	KCl	K	0.5244
	KCl	K <sub>2</sub> O	0.63168
	KBr	K	0.3285
	K <sub>2</sub> SO <sub>4</sub>	K	0.44870
	K <sub>2</sub> SO <sub>4</sub>	K <sub>2</sub> O	0.5405
	K <sub>2</sub> PtCl <sub>6</sub>	K	0.1609
	K <sub>2</sub> PtCl <sub>6</sub>	K <sub>2</sub> O	0.1941
	K <sub>2</sub> PtCl <sub>6</sub>	KCl	0.3071
	KClO <sub>4</sub>	K	0.28219
	KClO <sub>4</sub>	K <sub>2</sub> O	0.33992
	KClO <sub>4</sub>	KCl	0.53811
	K	K <sub>2</sub> O	1.2046
	KOH	K <sub>2</sub> CO <sub>3</sub>	1.2315
Rubidium, 85.44	Rb <sub>2</sub> SO <sub>4</sub>	Rb	0.6401
	Rb <sub>2</sub> PtCl <sub>6</sub>	Rb	0.2952
	Rb	Rb <sub>2</sub> O	1.0936
Selenium, 79.2	Se	SeO <sub>2</sub>	1.4040
	Se	SeO <sub>3</sub>	1.6060
Silicon, 28.06	SiO <sub>2</sub>	Si	0.4670
	SiO <sub>2</sub>	SiO <sub>3</sub>	1.2644
	SiO <sub>2</sub>	Si <sub>2</sub> O <sub>7</sub>	1.3996
	SiO <sub>2</sub>	SiO <sub>4</sub>	1.5328
	Si	SiO <sub>2</sub>	2.1404
Silver, 107.88...	AgCl	Ag	0.7526
	AgCl	Ag <sub>2</sub> O	0.80843
	AgBr	Ag	0.57445
	AgI	Ag	0.4595
	Ag	Ag <sub>2</sub> O	1.0742
Sodium, 22.997....	NaCl	Na	0.3934
	NaCl	Na <sub>2</sub> O	0.53026
	Na <sub>2</sub> SO <sub>4</sub>	Na	0.3238
	Na <sub>2</sub> SO <sub>4</sub>	Na <sub>2</sub> O	0.4364
	Na <sub>2</sub> CO <sub>3</sub>	Na	0.43395
	Na <sub>2</sub> CO <sub>3</sub>	Na <sub>2</sub> O	0.5849
	Na	Na <sub>2</sub> O	1.3479
Strontium, 87.62...	SrSO <sub>4</sub>	Sr	0.4770
	SrSO <sub>4</sub>	SrO	0.5641
	SrCO <sub>3</sub>	Sr	0.5936
	SrCO <sub>3</sub>	SrO	0.7019
	Sr	SrO	1.1826



GRAVIMETRIC FACTORS. *Continued*

	Given	Sought	Multiply by factor N
Sulphur, 32.065. ....	BaSO <sub>4</sub>	S	0.13736
	BaSO <sub>4</sub>	SO <sub>2</sub>	0.27444
	BaSO <sub>4</sub>	SO <sub>3</sub>	0.34299
	BaSO <sub>4</sub>	SO <sub>4</sub> •	0.41152
	BaSO <sub>4</sub>	H <sub>2</sub> SO <sub>4</sub>	0.42016
	S	SO <sub>2</sub>	1.9979
	S	SO <sub>3</sub>	2.4968
	S	H <sub>2</sub> SO <sub>4</sub>	3.0588
	Te	TeO <sub>2</sub>	1.2510
	Te	TeO <sub>3</sub>	1.3765
Tellurium, 127.5	Tl	Tl	0.6169
	Tl <sub>2</sub> PtCl <sub>6</sub>	Tl	0.5005
	Tl	Tl <sub>2</sub> O	1.0391
Thallium, 204.4. . .	ThO <sub>2</sub>	Th	0.8789
Thorium, 232.15	SnO <sub>2</sub>	Sn •	0.7877
	Sn	SnO <sub>2</sub>	1.2693
	TiO <sub>2</sub>	Ti	0.5995
Tin, 118.70. ....	WO <sub>3</sub>	W	0.7930
Titanium, 47.9. ....	U <sub>3</sub> O <sub>8</sub>	U	0.8481
	U <sub>3</sub> O <sub>8</sub>	UO <sub>2</sub>	0.9525
	UO <sub>2</sub>	U	0.8816
Tungsten, 184.0. . .	V <sub>2</sub> O <sub>5</sub>	V	0.5602
	V	V <sub>2</sub> O <sub>5</sub>	1.7849
	V	VO <sub>4</sub>	2.2559
Uranium, 238.17	ZnO	Zn	0.8034
	ZnS •	Zn	0.6709
	ZnS	ZnO	0.8351
	Zn <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	Zn	0.4289
	Zn	ZnO	1.2448
	ZrO <sub>2</sub>	Zr	0.7398 •
Vanadium, 50.96.	Pt	NH <sub>3</sub>	0.14450
	Pt	NH <sub>4</sub>	0.18483
	Pt	NH <sub>4</sub> OH	0.35906
Zinc, 65.38			
Zirconium, 91.0.			
Ammonia, 17.034.			

Calculated by International Atomic Weight Table of 1925, O = 16.

PROPERTIES OF PRECIPITATES<sup>1</sup>

Elements	Object	Obtained by or precipitated with	Obtained or precipitated as	Conditions of solution	Soluble in	Contaminants	Prepared for weighing by	Weighed as
K	Weighing.	Precipitant $\text{PtCl}_4$ . Precipitate preferably dissolved in hot $\text{H}_2\text{O}$ and evaporated in a weighed vessel.	$\text{K}_2\text{PtCl}_6$	Cold, alcoholic, containing chlorides or $\text{HCl}$ . Salts in other than $\text{NaCl}$ solution should be absent. Small amounts of $\text{Li}$ or $\text{Mg}$ may be present, but are detrimental. As above.	Slightly soluble in cold, more so in hot $\text{H}_2\text{O}$ . Insoluble in alcohol. Removed by washing with $\text{H}_2\text{O}$ + $\text{NH}_4\text{Cl}$ + $\text{K}_2\text{PtCl}_6$ .	$\text{NaCl}$ and other insoluble in alcohol.	Drying.	$\text{K}_2\text{PtCl}_6$
	Weighing.	Precipitant $\text{PtCl}_4$ .	$\text{K}_2\text{PtCl}_6$		As above.	As above.	Ignition gently at first. Addition of $\text{H}_2\text{C}_2\text{O}_4$ aids reduction. Ignition not above a dull red.	$\text{Pt}$ $\text{KCl}$
	Weighing.	Evaporation and gentle ignition. Volatile at temperatures above a dull red.	$\text{KCl}$	Only chlorides or salts converted to chlorides should be present. Ammonium salts may be present.	In water. Less in alcohol or strong $\text{HCl}$ .	$\text{NaCl}$ , and if long exposed to the air, organic dust.		
	Weighing.	Evaporation and ignition ( $\text{NH}_4)_2\text{CO}_3$ facilitates conversion.	$\text{K}_2\text{SO}_4$	Absence of salts forming non-volatile sulphates or containing non-volatile acids (as $\text{H}_3\text{PO}_4$ ).	Moderately in $\text{H}_2\text{O}$ , much less in alcohol.	$\text{Na}_2\text{SO}_4$ or other non-volatile sulphates.	Ignition over Bunsen flame.	$\text{K}_2\text{SO}_4$
Na	Weighing.	Evaporation and gentle ignition.	$\text{NaCl}$	Same as $\text{KCl}$ .	Same as $\text{KCl}$ .	$\text{KCl}$ and other salts (as sulphates insoluble in alcohol).	Ignition above a dull red.	$\text{NaCl}$

<sup>1</sup>Compiled mainly from an article by Prof. E. Waller, entitled "Properties of Precipitates," *School of Mines Quarterly*, Vol. XII, taken from Furman's "Manual of Practical Assaying."

	Weighting.	Same as $K_2SO_4$ .	$Na_2SO_4$	Same as $K_2SO_4$ .	Same as $K_2SO_4$ .	$K_2SO_4$ and other non-volatile sulphates.	Same as $K_2SO_4$ .	$Na_2SO_4$
Ca	Weighting.	Precipitant $(NH_4)_2C_2O_4$ or $H_2C_2O_4$ in $NH_4OH$ solution.	$CaC_2O_4$	Hot, strongly ammoniacal and an excess of oxalate.	Mineral acids, slightly in $H_2C_2O_4$ .	$MgC_2O_4$ , which is removed by solution in $HCl$ and reprecipitation. As above.	Ignition, gently at first and finally over blast-lamp. Addition of $H_2SO_4$ , evaporation, and ignition. In presence of $C$ add $HNO_3$ .	$CaO$
	Weighting.	As above.	$CaC_2O_4$	As above.	As above.	As above.		$CaSO_4$
	Separation.	Precipitant $(NH_4)_2CO_3$ .	$CaCO_3$	Alkaline solution free from large excess of alkaline salts, especially citrates.	$H_2O$ containing $CO_2$ . In acids in hot solution of $NH_4Cl$ . Insoluble in $H_2O + NH_4OH + (NH_4)_2CO_3$ .	$BaCO_3$ and $MgCO_3$ , if much are present.		
Mg	Weighting.	Precipitant $Na_2HPO_4$ .	$MgNH_4PO_4$	Cold, containing excess of $NH_4OH$ and $NH_4Cl$ . Absence of $SiO_2$ and bases other than alkalis.	Acids. Hot solutions and slightly in cold $H_2O$ . Insoluble in $NH_4NO_3$ .	$SiO_2$ and $Mg(OH)_2$ .	Ignition, gently at first, finally intensely. In presence of $C$ add $NH_4NO_3$ .	$Mg_2P_2O_7$
	Separation.	Precipitant $Ba(OH)_2$ .	$Mg(OH)_2$	Alkaline and moderately concentrated. Free from ammonium salts and organic salts.	Acids and ammonium salts. Prevented by organic salts.	Usually unimportant for purposes of separation.		
Ba	Weighting.	Precipitant $H_2SO_4$ . Should be heated before adding.	$BaSO_4$	Hot, containing some free $HCl$ . Absence of $SiO_2$ and large amounts of $(NH_4)_2S$ group and $Ca$ salts.	Conc. $H_2SO_4$ in strong hot $HCl$ and $HNO_3$ (dilute). In strong hot $FeCl_3$ and in alkaline or al-	Alkaline and alkali-earth chlorides, chlorates, sulphates, nitrates, basic, ferric, or aluminic compounds.	Ignition. In the presence of $C$ the addition of $HNO_3$ is necessary.	$BaSO_4$

PROPERTIES OF PRECIPITATES. *Continued*

Elements	Object	Obtained by or precipitated with	Obtained or precipitated as	Conditions of solution	Soluble in	Contaminants	Prepared for weighing by	Weighed as
Ba					kali-earth nitrates. In chloride solutions.	Repeated boiling in very dilute HCl assists in removal, but liable to dissolve some of the precipitate. $\text{MgCO}_3$ if much is present, and carbonates of the fixed alkalis.		
	Separation.	Precipitant $(\text{NH}_4)_2\text{CO}_3$ .	$\text{BaCO}_3$	Alkaline, containing $\text{NH}_4\text{OH}$ and in excess of $(\text{NH}_4)_2\text{CO}_3$ .	$\text{H}_2\text{O}$ containing $\text{CO}_2$ and acids. In hot $\text{NH}_4\text{Cl}$ . Insoluble in $\text{NH}_4\text{OH} + (\text{NH}_4)_2\text{CO}_3$ .			
Fe	Weighting.	Precipitant $\text{NH}_4\text{OH}$ . Addition of $\text{NH}_4\text{Cl}$ aids precipitation.	$\text{Fe}_2(\text{OH})_6$	Alkaline, and free from $\text{H}_2\text{S}$ .	Mineral acids and solutions containing citric, tartaric acids, etc., or organic substances (as sugar).	Basic ferric salts $\text{Cr}$ , $\text{P}_2\text{O}_5$ , $\text{Al}$ , $\text{Mn}$ , $\text{Co}$ , $\text{Ni}$ , $\text{Mg}$ , $\text{SiO}_2$ , etc.	Ignition. In presence of $\text{C}$ , $\text{HNO}_3$ , or $\text{NH}_4\text{NO}_3$ should be added. Volatile in presence of chlorides.	In $\text{Fe}_2\text{O}_3$
	Separation.	As above.	$\text{Fe}_2(\text{OH})_6$	As above.	As above.	As above.		
	Separation.	Precipitant $\text{Na}_2\text{C}_2\text{H}_3\text{O}_2$ . Filtered hot.	$\text{Fe}_2(\text{OH})_6$ $(\text{C}_2\text{H}_3\text{O}_2)_6$	Dilute containing but little free $\text{H}_2\text{C}_2\text{H}_3\text{O}_2$ . Hot, but too long boiling should be avoided.	In cold mineral acids. Also in alkalies or $\text{Al}$ , $\text{Cr}$ , $\text{Co}$ , $\text{Ni}$ , $\text{Zn}$ , $\text{Mn}$ , $\text{Cu}$ , etc. Resoluble by resolu-	Salts of fixed alkalis, $\text{SiO}_2$ , $\text{P}_2\text{O}_5$ .		

Fe	Weighting.	Precipitant (usual) $\text{NH}_4\text{OH}$ . Beat precipitated by adding slight excess $\text{NH}_4\text{OH}$ , boiling, and passing $\text{H}_2\text{S}$ . Same as Fe.	$\text{Al}_2(\text{OH})_6$ ( $\text{C}_2\text{H}_3\text{O}_2$ ) <sub>3-4</sub>	avoided.	insoluble in hot very dilute $\text{HCl}$ , $\text{H}_2\text{O}_2$ .	Ignition. Slightly volatile in presence of $\text{NH}_4\text{Cl}$ .	$\text{Al}_2\text{O}_3$
Al	Separation.		$\text{Al}_2(\text{OH})_6$ ( $\text{C}_2\text{H}_3\text{O}_2$ ) <sub>3-4</sub>	Neutral or slightly alkaline, containing preferably $\text{NH}_4\text{Cl}$ .  Same as Fe. No free acetic acid should be present.	Acids and fixed alkalis. Slightly in cold $\text{NH}_4\text{OH}$ . Tartrates, Mn, etc. Removed by resolution and e.g., prevent precipitation.  Same as Fe, except slightly soluble in hot dilute $\text{HCl}$ , $\text{H}_2\text{O}_2$ .	Basic Al salts: $\text{SiO}_2$ , $\text{P}_2\text{O}_5$ , $\text{Al}_2\text{O}_3$ , $\text{Cr}$ , $\text{Co}$ , $\text{Ni}$ , $\text{Zn}$ , etc. Removed by resolution and e.g., prevent precipitation.  Same as Fe.	$\text{Al}_2\text{O}_3$
Cr	Weighting	Precipitant $\text{NH}_4\text{OH}$ Excess removed by boiling.	$\text{Cr}_2(\text{OH})_6$	Absence of members of the $(\text{NH}_4)_2\text{S}$ group, and preferably all non-volatile salts. Solution must be neutral.	All acids, in $\text{NaOH}$ , $\text{KOH}$ , and slightly in $\text{NH}_4\text{OH}$ . Tartrates, citrates, sugar, etc., prevent precipitation.	Ignition	$\text{Cr}_2\text{O}_3$
Ti	Weighting	Insoluble form by boiling the solution acidified with $\text{H}_2\text{SO}_4$ .	$\text{H}_2\text{TiO}_3$	Dilute containing but little free $\text{H}_2\text{SO}_4$ . Chlorides must be absent. $\text{HCl}$ and $\text{H}_2\text{SO}_4$ facilitate precipitation. Prolonged boiling also. Long fusion with $\text{Na}_2\text{CO}_3$ at high temperature.	Soluble form same as $\text{Fe}_2(\text{OH})_6$ . Insoluble form by fusion with $\text{KOH}$ , or boiling with $\text{SO}_2$ , and reduction with conc. $\text{HCl}$ or $\text{H}_2\text{SO}_4$ .  Acids Slightly in $\text{H}_2\text{O}$ .	Ignition with addition of $(\text{NH}_4)_2\text{CO}_3$ .	$\text{TiO}_2$
	Separation.	Fusion and leaching until filtrate runs cloudy.	( $\text{xNa}_2\text{O}$ , $\text{TiO}_2$ )- $\text{Na}_2\text{TiO}_3$		$\text{Fe}_2\text{O}_3$ , $\text{Al}_2\text{O}_3$ , $\text{SiO}_2$ , and $\text{P}_2\text{O}_5$ ; $\text{Fe}_2\text{O}_3$ removed by re-solution, reduction with $\text{SO}_2$ , and precipitation in presence of $\text{HCl}$ .  $\text{H}_2\text{O}_2$ , $\text{Fe}_2\text{O}_3$ , acid-soluble silicate, alkali-earth carbonates, etc.		

PROPERTIES OF PRECIPITATES. *Continued*

Elements	Object	Obtained by or precipitated with	Obtained as precipitate	Conditions of solution	Soluble in	Contaminants	Prepared for weighing by	Weighed as
Zn	Weighing.	Precipitant: $\text{Na}_2\text{CO}_3$ .	$2\text{ZnCO}_3$ , $\text{Zn}(\text{OH})_2$ .	Absence of caustic and bicarbonate alkalies and ammonium salts.	Dilute acids, fixed caustic alkalies, bicarbonates, and organic solutions.	Alkaline carbonate removed by repeated washing with hot $\text{H}_2\text{O}$ . $\text{Fe}_2\text{O}_3$ , $\text{Al}_2\text{O}_3$ , and $\text{SiO}_2$ removed by solution and precipitation of the ignited $\text{ZnO}$ .	Ignition; absence of C is necessary.	$\text{ZnO}$
	Separation.	Precipitant: $\text{H}_2\text{S}$ in boiling dilute $\text{HCl}$ ; $\text{H}_2\text{O}$ solution. $\text{NH}_4\text{Cl}$ facilitates precipitation.	$\text{ZnS}$ , $\text{II}_2\text{O}$ .	Alkaline, or acid only with weak organic acid. Free mineral acids prevent precipitation ( $\text{H}_2\text{SO}_4$ , least). Fe should be absent.	Dilute $\text{HCl}$ and $\text{HNO}_3$ , strong $\text{H}_2\text{SO}_4$ when not moved by resolution, neutralizing, and reprecipitation. Fe if not previously removed.	Mn, Co, and Ni sulphides. Resolved by resolution, neutralizing, and reprecipitation. Fe if not previously removed.		
Mn	Weighing.	Precipitant: $\text{NaNH}_2\text{HPO}_4$ in presence of ammonium salts.	$\text{MnNH}_4\text{PO}_4$ .	Mn must be entirely in manganous form, and slightly alkaline. An excess of phosphate is necessary. Oxalates and excessive amounts of ammonium salts should be absent.	Acids. Slightly in large excess of ammonium salts. The influence of ammonium salts is lessened by large excess of the precipitant.	None if bases forming insoluble phosphates are absent and precipitate is well washed.	Ignition. Gen-ly at first.	$\text{Mn}_2\text{P}_2\text{O}_7$
	Separation.	Br from acetate solution $\text{KClO}_4$ from boiling nitric acid solution.	$\text{MnO}_2$ .	Absence of $\text{HCl}$ or other halogen acids (especially $\text{HCl}$ ). Insoluble oxides of nitrogen in strong $\text{HCl}$ or reducing agents. $\text{H}_2\text{O}_2$ and conc. $\text{HNO}_3$ . Boiling necessary.	Dilute mineral acids (especially $\text{HCl}$ ). Insoluble in strong $\text{HCl}$ or reducing agents. $\text{H}_2\text{O}_2$ and conc. $\text{HNO}_3$ .	Salts of fired alkalies, $\text{Fe}_2\text{O}_3$ , $\text{ZnO}$		

Ni	Weighing.	Electrolysis.	Ni	Absence of all other metals of $\text{H}_2\text{S}$ and $(\text{NH}_4)_2\text{S}$ groups. Ni present as oxalate, sulphate, or double ammonium nitrate, and excess of $\text{NH}_4\text{OH}$ . Bases other than fixed alkalis should be absent.	Readily in $\text{HNO}_3$ . Slowly in strong $(\text{NH}_4)_2\text{C}_2\text{O}_4$ .	Co, Fe and Zn, unless previously separated.	Drying at gen-Ni the heat. (See Cu.)
Co	Weighting.	Precipitant $\text{KOH}$ or $\text{NaOH}$ .	$\text{Ni}(\text{OH})_2$ .	Absence of other members of the $\text{H}_2\text{S}$ or $(\text{NH}_4)_2\text{S}$ groups. $\text{NH}_4\text{Cl}$ aids precipitation.	Mineral acids. In ammonium salts, tartrates, citrates, etc. Precipitation prevented by a number of groups, if not previously removed.	Alkalies, $\text{Fe}_2\text{O}_3$ , $\text{Al}_2\text{O}_3$ , and $\text{SiO}_2$ strongly.	Ignition $\text{NiO}$ .
	Separation.	Precipitant $\text{H}_2\text{S}$ in weak $\text{HCl}$ solution.	$\text{NiS}$ , $\text{H}_2\text{O}$ .				
	Weighting. Separation.	Precipitant $\text{KNO}_3$ in solution slightly acid with $\text{HCl}$ . Electrolysis. Same as $\text{NiS}$ , $\text{H}_2\text{O}$ .	$6\text{KNO}_3$ , $\text{Co}_2(\text{NO}_2)_6$ , $\text{CoS}$ , $\text{H}_2\text{O}$ .	Warm, containing only $\text{Co}$ , $\text{Ni}$ , and $\text{K}$ salts, and nearly saturated with $\text{K}_2\text{C}_2\text{H}_3\text{O}_2$ . Same as $\text{Ni}$ .	$\text{H}_2\text{O}$ , acids, $\text{NH}_4$ , and $\text{Na}$ salts. Insoluble in dilute $\text{HCl}$ , $\text{H}_2\text{O}_2$ , and alcohol. Same as $\text{Ni}$ .	$\text{Ca}$ and $\text{Pb}$ if present. $\text{K}$ salts should be removed by careful washing. Same as $\text{Ni}$ .	Dissolve in dilute $\text{H}_2\text{SO}_4$ , and evaporate in a weighed vessel. Ignition. Same as $\text{Ni}$ . $3\text{K}_2\text{SO}_4 \cdot \frac{1}{2} 2\text{CoSO}_4$ .  Co
Cu	Weighting.	Electrolysis.	$\text{Cu}$ .	$\text{H}_2\text{SO}_4$ solution containing a few drops of $\text{HNO}_3$ .	$\text{HNO}_3$ and $\text{HCl}$ . Deposit prevented by $\text{Cl}$ .	$\text{As}$ , $\text{Sb}$ , or $\text{Bi}$ , if $\text{HNO}_3$ is not present. If $\text{HNO}_3$ and with alcohol.	Washing with $\text{H}_2\text{O}$ and then with alcohol.

PROPERTIES OF PRECIPITATES. *Continued*

Elements	Object	Obtained by or precipitated with	Obtained or precipitated as	Conditions of solution	Soluble in	Contaminants	Prepared for weighing by	Weighed as
Cu	Separation.	Precipitant: $\text{H}_2\text{S}$ in dilute acid solution	Precipitant: $\text{CuS}$	preferable. Organic acids should be absent.	too strong acid, or lower oxides of nitrogen.	Zn are present, Zn will begin to precipitate as soon as Cu is all precipitated.	Drying at a temperature which can be borne by the hand.	
				Moderately strong $\text{HCl}$ or $\text{H}_2\text{SO}_4$ . If $\text{HNO}_3$ is present, the solution must be cold and dilute	Hot dilute $\text{HNO}_3$ and strong hot $\text{HCl}$ .	Other members of the $\text{H}_2\text{S}$ group.		
Pb	Weighing.	Precipitant: $\text{H}_2\text{SO}_4$	Precipitant: $\text{PbSO}_4$	Excess of $\text{H}_2\text{SO}_4$ and but little $\text{HNO}_3$ or $\text{HCl}$ . $\text{NH}_4$ salts and salts of organic acids must be absent	Conc. mineral acids; in $\text{NH}_4$ salts, and especially those of organic acids.	Other sulphates, which are removed by washing with very dilute $\text{H}_2\text{SO}_4$ .	Ignition. If $\text{C}$ is present, treat with $\text{HNO}_3$ , evaporate, and ignite.	$\text{PbSO}_4$
	Weighing.	Precipitant: $\text{K}_2\text{Cr}_2\text{O}_7$ in acetic-acid solution.	Precipitant: $\text{PbCrO}_4$	Bi, Ag, Fe, and Ba should be absent. Chlorides should be absent, and also alkaline citrates, tartrates, etc.	Moderately strong mineral acids; in hot $\text{NH}_4\text{C}_2\text{H}_3\text{O}_2$ , insoluble in dilute $\text{HNO}_3$ .	Ba, Bi, Hg and chromates. If much Fe is present, possibly $\text{Fe}(\text{CrO}_4)_2$ .	Drying on pre-viously weighed filter.	$\text{PbCrO}_4$
	Separation.	Precipitant: $\text{H}_2\text{S}$ .	Precipitant: $\text{PbS}$	Slightly acid, neutral, or alkaline. Best precipitated in cold $\text{H}_2\text{SO}_4$ solution.	Dilute boiling $\text{HNO}_3$ ; hot conc $\text{HCl}$ . In $\text{NaF}$ solution.	Other members of the $\text{H}_2\text{S}$ group if present.		



Ag	Weighting.	Precipitant HCl in very slight excess.	Slightly acid with $\text{HNO}_3$ , free from chlorides.	Partially in strong hot HCl or $\text{HNO}_3$ . Partially in alkaline and alkaline-earth chlorides. Readily in $\text{NH}_4\text{OH}$ , $\text{KCN}$ , and $\text{Na}_2\text{S}_2\text{O}_3$ . Same as $\text{AgCl}$ . Insoluble in considerable excess of precipitant.	Chlorides of Pb and Hg if present in the solution.	Ignition until $\text{AgCl}$ the edges fuse. Volatile at a temperature slightly above dull red.
	Separation.	Precipitant $\text{NaBr}$ .	Same as $\text{AgCl}$ .			
As	Weighting.	Precipitant $\text{H}_2\text{S}$ in $\text{HCl}$ .	Acid with mineral acid (preferably $\text{HCl}$ ).	Soluble in alkaline hydrates, carbonates, and sulphides. In $\text{KHSO}_4$ , in aqua regia, and in $\text{H}_2\text{O} + \text{Cl}$ or $\text{H}_2\text{O} + \text{Br}$ .	Other sulphides of Hg group if present.	Drying. Volatile as $\text{As}_2\text{S}_3$ upon ignition.
	Weighting.	Precipitant $\text{MgCl}_2$ in ammoniacal solution containing alcohol.	Alkaline with $\text{NH}_4\text{OH}$ , containing a minimum of $\text{NH}_4\text{Cl}$ and 30 per cent alcohol.	In warm acids. In $\text{H}_2\text{O} + \text{NH}_4\text{Cl}$ . Insoluble in $\text{NH}_4\text{OH} + \text{alcohol}$ .	Basic Mg salts, sulphates, and other salts insoluble in $\text{NH}_4\text{OH} + \text{alcohol}$ .	Dissolving the precipitate in $\text{HNO}_3$ into a weighed vessel, evaporating, and igniting slowly at first.
Sb	Weighting.	Precipitant $\text{H}_2\text{S}$ in acid solution, or upon acidifying solutions of sulphur antimonite.	Slightly acid and moderately dilute.	Moderately concentrated acids ( $\text{HCl}$ especially). Tartaric acid assists precipitation, and washing with fixed alkalis or alkaline sulphides.	S generally accompanies the precipitate; removed by replacing the $\text{H}_2\text{O}$ by alcohol, red. $\text{CS}_2$ .	Mixed with 50 times its weight of $\text{H}_2\text{O}$ and ignited to dull red.

• PROPERTIES OF PRECIPITATES. *Continued*

Elements	Object	Obtained with or precipitated by	Obtained or precipitated as	Conditions of solution	Soluble in	Contaminants	Prepared for weighing by	Weighed as
Sn	Weighing.	Precipitant: $\text{H}_2\text{S}$ in acid solution or upon acidifying solutions of alkaline sulphates and a nate.	$\text{SnS}_2$	Moderately dilute and slightly acid. Precipitation promoted by acetates and inter-fered with by oxalates or oxalic acid.	Moderately strong acids of H <sub>2</sub> S group, if especially present. Separately with free ac-cess of air. Ad-dition of $\text{HNO}_3$ aids conversion.	Other members of H <sub>2</sub> S group, if especially present. Separately with free ac-cess of air. Ad-dition of $\text{HNO}_3$ aids conversion.	Heating mod-erately and slow-ly with free ac-cess of air. Ad-dition of $\text{HNO}_3$ aids conversion.	$\text{SnO}_2$
P	Weighing. Separation and titration.	$\text{MgCl}_2$ in am-moniacal solu-tion containing $\text{NH}_4\text{Cl}$ . Precipitant: $(\text{NH}_4)_2\text{MoO}_4$ in $\text{HNO}_3$ solution heated to $80^\circ\text{C}$ . Agitation facili-tates precipita-tion.	$\text{MgNH}_4\text{-PO}_4$ $12\text{MoO}_4\text{-}(\text{NH}_4)_2\text{PO}_4$	Same as Mg  Acid with $\text{HNO}_3$ and containing an excess of $\text{NH}_4\text{NO}_3$ and precipitant. Chlorides, $\text{HCl}$ , re-ducing agents and organic acids should be absent.	Same as Mg.  $\text{NH}_4\text{OH}$ and al-kalies. Soluble in $\text{HCl}$ and mod-erately strong $\text{H}_2\text{SO}_4$ or $\text{HNO}_3$ . In hot $\text{H}_2\text{O}$ . In-dilute $\text{HNO}_3$ containing $\text{NH}_4\text{-NO}_2$ .	Same as Mg.  Arseno-molyb-date, $\text{SiO}_2$ , $\text{Fe}_2\text{O}_3$ and $\text{TiO}_2$ .	Same as Mg.  For titration by dissolving in $\text{NH}_4\text{OH}$ and re-ducing by $\text{Zn} + \text{H}_2\text{SO}_4$ , or by acidimetry.	$\text{Mg}_2\text{P}_2\text{O}_7$
S, $\text{SO}_3$ , $\text{SO}_2$ , etc.	Weighing.	Precipitant: $\text{BaCl}_2$ in hot solu-tion containing a little free $\text{HCl}$ .	$\text{BaSO}_4$	Same as $\text{BaSO}_4$ .	Same as $\text{BaSO}_4$ .	Same as $\text{BaSO}_4$ .	Same as $\text{BaSO}_4$ .	$\text{BaSO}_4$
Cl	Weighing.	Precipitant: $\text{AgNO}_3$ .	$\text{AgCl}$	Same as Ag.	Same as Ag.	Same as Ag.	Same as Ag.	$\text{AgCl}$

Si and SiO <sub>2</sub>	Byevaporation of acid solution to dryness and heating at 115° to 120°C., or by evaporation of H <sub>2</sub> SO <sub>4</sub> solution to fumes of SO <sub>3</sub> .	2H <sub>2</sub> O, SiO <sub>2</sub>	Should contain HCl. If much fixed alkalis, HNO <sub>3</sub> is present. By fusion with should be removed fixed alkalis conc. H <sub>2</sub> SO <sub>4</sub> . Also present is deter- by adding HCl (caustic or car- and boiling. bonate). Insol- uble in H <sub>2</sub> O and Al <sub>2</sub> O <sub>3</sub> and Fe <sub>2</sub> O <sub>3</sub> . HF and H <sub>2</sub> SO <sub>4</sub> . acids (HF ex- cepted).	Boiling caustic phates, removed by digestion with impurities are H <sub>2</sub> SO <sub>4</sub> . Also present is deter- by adding HCl (caustic or car- bonate). Insol- uble in H <sub>2</sub> O and Al <sub>2</sub> O <sub>3</sub> and Fe <sub>2</sub> O <sub>3</sub> . HF and H <sub>2</sub> SO <sub>4</sub> . acids (HF ex- cepted).	Insoluble s u l - Ignition after drying. When
C, CO <sub>2</sub> , etc.	Absorption with KOH, Na- OH, or Ca(OH) <sub>2</sub> + NaOH.	Na <sub>2</sub> CO <sub>3</sub> , K <sub>2</sub> CO <sub>3</sub> or Na <sub>2</sub> CO <sub>3</sub> + CaCO <sub>3</sub> .	.....	H <sub>2</sub> O and CO <sub>2</sub> from the atmos- phere Prevented by suitable ab- sorption appara- tus.	CO <sub>2</sub>
N	PtCl <sub>4</sub> .	(NH <sub>4</sub> ) <sub>2</sub> Pt- Cl <sub>6</sub>	Same as K <sub>2</sub> Pt- Cl <sub>6</sub> .	Same as K <sub>2</sub> Pt- Cl <sub>6</sub> .	Ignition to Pt. (See K <sub>2</sub> PtCl <sub>6</sub> ).

QUANTITATIVE PRECIPITATION OF METALS BY ELECTROLYSIS<sup>1</sup>

Solution	Au	Pt	Pb	Ag	Hg	Pd	Sb	Sn	Cu	Bi	Cd	Tl	Fe	Mn	Zn	Co	Ni	Se
Nitric, or sulphuric . . . . .	-	-	-	-	-	+	(a)	-	-	-	-	+	(b)	+	(c)	(d)	-	..
Double ammon. oxalate . . . . .	-	-	-	-	-	-	-	-	-	-	-	-	-	+	(e)	-	-	..
Double ammon. sulphate . . . . .	-	-	-	-	-	-	-	-	-	-	-	-	-	+	(f)	-	-	..
Double potass. cyanide . . . . .	-	-	-	-	-	-	-	-	-	-	-	-	-	+	(g)	-	-	..
Sulpho-salt . . . . .	-	-	-	-	-	-	-	-	-	-	-	-	-	+	(h)	-	-	..
Glacial phosphoric acid after $(\text{NH}_4)_2\text{CO}_3$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	..

<sup>1</sup> KAHN and WOODGATE, "Journ. Soc. Chem. Ind.," Vol. VIII p. 256.

- Precipitated on cathode as metal

+ Precipitated on anode.

(a) On anode as  $\text{PbO}_2$ .(b) On anode as  $\text{Ti}_2\text{O}_3$ .(c) On anode as  $\text{MnO}_2$ .

(d) From alkaline or neutral solution.

(e) Potass. salt preferable

(f) Incompletely. Completely from potass. salt

(g) After adding  $\text{Na}_2\text{C}_2\text{H}_3\text{O}_7$  and  $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ .

(h) Incompletely.

(i) DOCTOR KELLER (private communication) called attention to the precipitation of selenium as metal at both cathode and anode. This seems to be the only case where this is true

## SECTION VI

### ORE DRESSING

#### CRUSHING

Stamps, Chilean mills and rolls are used for coarse crushing; feed generally not over 2 in. and discharge screen about 35 to 40 mesh. The roll makes less fines in the product than either of the others. HARDINGE mill is a stage crusher; feed about  $\frac{3}{4}$  in.; product uniform fine sand with but little slime; HUNTINGTON mill, regrinding machine; best feed not over  $\frac{1}{4}$  in., makes considerable slime. Tube mill is best and only logical fine grinding machine.

**Abbé Tube Mill.**—The original ABBÉ gear-driven mill was supported on a pair of riding rings. The distinguishing feature was a spiral of Archimedes through which the ore was fed and discharged. Tube mills now supported either on riding rings or trunnions. Early tendency was toward long mill of small diameter, 22 ft. by  $3\frac{1}{2}$  ft., now changing to 5 and 6 ft. diameter and 16 to 18 ft. long. Grinding effected by flint pebbles fed into mill. (See Ball mill.)

**Amalgamating Plan.**—This is a flat-bottomed iron pan with an iron cone in the center, with high sides, nearly or quite vertical, and in it a horizontal, annular disk, called a muller, is revolved. Many authorities claim that this should not be used as a grinder, but only as an amalgamator. From 3 to 5 hp. is needed for amalgamating, and 5 to 10 hp. for grinding in a 5-ft. pan.

**Arrastre.**—A machine having horizontal surfaces grinding concentrically on a vertical shaft. In its original form it consists of a circular pavement from 6 to 20 ft. in diameter with a retaining wall around it and a step in the center. Upon the steps stands a vertical revolving spindle from which extend horizontal arms, to which large boulders, called dragstones, are attached by chains.

**Ball Mill.**—Short tube mill (*q.v.*) of relatively large diameter in which grinding is done by steel balls instead of pebbles. Wet grinding with steel balls formerly considered unwise due to excessive steel consumption now coming into favor.

According to an investigation made by A. N. Gow, A. B. Campbell and W. H. Coghill, a ball mill speed of 65 per cent. of the critical speed gives the maximum grinding capacity, and a speed of 50 per cent. of the critical speed gives the most efficient grinding (*Trans. A. I. M. E., San Francisco meeting, 1929*).

**Beater Mill.**—In this classification may be included hammer mills, ring mills and beater-blade mills. The mill consists of a shaft carrying one or more spiders or rotors on which is mounted the beaters or hammers. The material is pulverized by the impact of the hammers, which may have a tip speed as high as 20,000 lin. ft. per min. The rotors are surrounded by a housing, the lower half of which is made up of perforated metal, grids, or grate bars. Hammer mills should be used for crushing to a moderate degree of fineness only. When pulverizing a hard or crystalline product, the maximum efficiency is obtained when about 50 per cent. passes a 100-mesh screen or 30 per cent. passes 200 mesh.

**Blake Crusher.**—Original crusher of jaw type. Rock is crushed between two jaws set at an angle to each other, one fixed and the other swinging from top suspension rod. Motion imparted to lower end of crushing jaw by toggle joint operated by eccentric. (See also DODGE crusher.)

**Bryan Mill.**—A form of Chilean mill using three rollers instead of two. The wear seems a little more even in this type of mill than in the HUNTINGTON or the regular Chilean.

**Burrstone Mill.**—This is sometimes known as a "rock-emery" mill. There are two stone faces which may rotate in opposite directions or one may be stationary. This mill is used only on very soft materials, pigments and the like.

**Chilean Mill (Edge Runner).**—These mills have vertical rollers running in a circular enclosure with a stone or iron base or die. They are of two classes: (a) those in which the rollers gyrate around a central axis, rolling upon the die as they go (the true Chile mill); (b) those in which the enclosure or pan revolves, and the rollers, placed on a fixed axis, are in turn revolved by the pan. It was formerly used as a coarse grinder, but is now used as a fine. According to Luther W. Lennox the Chilean mill should not be used for grinding six-mesh sands without some admixture of  $1\frac{1}{2}$ -to  $2\frac{1}{2}$ -in. material, and to neglect of this is due much of the present unpopularity of the Chilean mill (*Bull. A.I.M.E.*, September, 1919, p. 2864).

**Differential Rolls.**—These consist of rolls rotating in opposite directions, or in the same direction with different peripheral speeds.

**Dodge Crusher.**—Similar to BLAKE crusher (*q.v.*) except movable jaw is hinged at bottom. Therefore discharge opening is fixed giving a more uniform product than BLAKE with its discharge opening varying every stroke, but this decreases capacity.

**Dodge Pulverizer.**—A hexagonal barrel revolving on a horizontal axis, containing perforated die plates and screens. Pulverizing is done by steel balls inside barrel.

**Edge Runner.**—See Chilean mill.

**Fuller-Lehigh Pulverizing Mill.**—For coal dust pulverizing only. Used by the Pennsylvania Steel Co., at Lebanon, Penn.

**Gardner Crusher.**—A swing-hammer crusher, the hammers being flat U-shaped pieces hung from trunnions between two

disks keyed to a shaft. When revolved, centrifugal force throws hammer out against feed and heavy anvil inside crusher housing.

**Griffin Roller Mills.**—A centrifugal mill, like the HUNTINGTON except there is one roller only (see "HUNTINGTON"). The mill is consequently unbalanced and requires a very solid foundation.

**Gyratory Crusher.**—Consists of a vertical spindle the foot of which is mounted in an eccentric bearing. The top carries a conical crushing head revolving eccentrically in a conical shell. There are three types of gyratory: those which have the greatest movement on the smallest lump; those that have equal movement for all lumps; those that have greatest movement on largest lump.

**Hammer Mill.**—See Beater mill.

**Hardinge Mill.**—This is a tube mill made with two conical sections connected by a central very short cylinder. The cone at the feed end is very short so that the large pebbles settle and grind at the large end where the feed is coarse.

**Huntington Mill.**—This operates by the centrifugal force of steel rollers revolving against the inner surface of a heavy horizontal steel ring or die. The rollers are suspended upon rods from horizontal arms by short trunnions allowing a swing of the rod and roller in a direction radial from the central vertical shaft.

**Jeffrey Swing-hammer Crusher.**—In an iron casing a shaft revolves carrying swinging arms having a free arc movement of 120°. The rotation of the driving shaft causes the arms to swing out and strike the coal or other brittle material, which, when sufficiently fine, passes through the grated bottom.

**Kent Roller Mill.**—This consists of a revolving steel ring with three rolls pressing against its inner face. The rolls are supported on springs, and the rings support the roll, so that there is some freedom of motion. The material to be crushed is held against the ring by centrifugal force.

**Kinthead Mill.**—This is a pan mill with a convex conical bottom on which a muller, having two surfaces of different inclinations, grinds. The machine acts on the gyratory principle as regards crushing between the surfaces.

**Krupp Ball Mill.**—This is the classic ball mill. Grinding was done by chilled-iron or steel balls of various sizes which ground against each other and the die ring, composed of five perforated spiral plates, each of which lapped the next. This formed steps which gave the balls a drop from one plate to the next, and in addition, gave a space through which oversize was returned. Outside the die-plate is a coarse perforated screen to take the chief wear, while outside that come fine gauze screens. The fines discharge through these into the housing inside which the screens revolve and which has a hopper bottom.

**Lane Mill.**—A slow-speed roller mill of the Chilean type. A horizontal spider carrying six rollers revolves slowly in pan 10 ft. or more in diameter making about 8 r.p.m. Advantages:

great crushing weight, low power, decreased wear due to slow speed.

**Marathon Mill.**—A form of tube mill used in the cement industry, in which the pulverizing is done by long pieces of hardened steel shafting.

**Marcy Mill.**—A ball mill in which a vertical diaphragm is placed about 1 ft. from the discharge end. Between this perforated diaphragm and the end of the tube there are arranged screens for sizing the material, oversize being returned for further grinding while undersize is discharged.

**Test of Hardinge vs. Marcy Mill at Inspiration.**—According to C. T. VAN WINKLE, *Bull. A.I.M. E.*, January, 1918, p. 175, when the Inspiration Copper Co., in 1917, tried out the Hardinge and Marcy Mills in parallel, results were favorable to the Marcy mill. The Marcy mills, each took feed direct from the bin and in closed circuit with a 6-ft. Dorr classifier, made a finished product. The Hardinge mills were arranged in tandem, the first mill taking coarse feed from the bin; its product going to a Dorr classifier, the sands from which went to the second Hardinge mill working in closed circuit with the second Dorr classifier.

SCREEN ANALYSIS OF MILL FEED

	Per cent.	Cum. per cent.
On 1.5 in. . . . .	17.7	17.7
On 1 in. . . . .	16.5	34.2
On $\frac{3}{8}$ in. . . . .	24.7	58.9
On 3 mesh. . . . .	7.3	66.2
On 6 mesh. . . . .	7.7	73.9
On 8 mesh. . . . .	2.2	76.1
On 14 mesh. . . . .	4.8	80.9
On 28 mesh. . . . .	3.6	84.5
On 48 mesh. . . . .	2.9	87.4
On 100 mesh. . . . .	2.3	89.7
On 200 mesh. . . . .	1.5	91.2
Through 200 mesh . . . . .	8.8	100.0
	100.0	

MR. VAN WINKLE suggests operations with the Hardinge mill are improved if the feed is through the smaller end. He believes the Marathon mill has not had the attention it deserves where fine crushing without sliming is considered desirable.

**Nissen Stamps.**—This is a gravity stamp with an individual circular mortar for each stamp.

**Rolls.**—Two cylinders, with faces much less than the diameters, revolving toward each other, drawing the material in between the crushing peripheries. One roll at least usually runs



in fixed bearings, the other may or may not run in movable bearings held by springs.

**Ring-roll Mills.**—See Roller Mills.

**Roller Mills.**—In this type of mill the material is ground between a stationary grinding ring and rolls or balls. They may be divided into ring-roll mills and centrifugal roll mills. In the former a vertical ring is supported on three rolls that maintain a pressure against it. This pressure may be varied by means of springs. In centrifugal roll mills the material is ground between a stationary grinding ring and rolls or balls which revolve and roll on the grinding ring.

**Roll Jaw Crusher.**—Same general type as BLAKE and DODGE (*q.v.*), but moving jaw has rolling instead of oscillating motion.

**Stamp Battery.**—In effect a heavy iron pestle working mechanically in a huge iron mortar. Generally grouped in units of five per mortar. Stamps vary up to 2000 lb. in weight, dropping 6 to 8 in. over 100 times per minute.

**Sturtevant Balanced Rolls.**—All four boxes are movable and held in position by springs. The idea is to divide the thrust whenever the springs yield and, by dividing by two the distance the roll must move, to reduce internal stresses.

**Sturtevant Grinder.**—A disk grinder in which one disk is stationary and the other rotates. The stationary disk is moved out of center from time to time, so that any groove which forms can be ground out.

**Sturtevant Roll Jaw Crusher.**—A crusher in which the motion of the upper part of the jaws is very like that of the DODGE crusher, while the lower parts of the jaws, two cylindrical surfaces of varying radii, grind the ore between them.

**Sturtevant Ring-roll Crusher.**—Works as does the KENT roller mill, which see.

**Symons' Disk Crusher.**—A mill in which the crushing is done between two cup-shaped plates which revolve on shafts set at a small angle to each other. These disks revolve with the same speed in the same direction and are so set as to be widest apart at the bottoms. Feed is from the center and the material is gradually crushed as it nears the edge, and is then thrown out by centrifugal force. See also p. 443.

**Williams Hinged-hammer Crusher.**—A machine similar to the JEFFREY machine. There is a rotating central shaft carrying a number of hinged hammers, which fly out from centrifugal force, crushing the feed against the casing.

**For preventing rapid abrasion of grinding surfaces,** B. E. FIELD recommends welding a thin layer of Haynes Stellite where the wear would come. He also recommends the same procedure for drag-chain links and along the edges of screw conveyors. (*Chem. Met. Eng.*, February, 1928, p. 96.)

### Crushing with Jaw Crushers

The jaw crusher is probably still the most popular method of reducing the size of ore. A table is given below of what has

actually been done with jaw crushers, taken from RICHARDS' "Ore Dressing," but the ordinary table of manufacturer's figures on crusher outputs, etc., is omitted for reasons given in part of the general discussion by MILTON H. HELLER in the *Engineering and Mining Journal*, Feb. 27, 1915.

When it is observed that the material fed to crushers is for the most part wet, as it comes from the mine, or dampened to reduce the dust, it is apparent the water exerts a lubricating action, which is further augmented should any clayey material be present. This condition might at any time bring the coefficient of friction down to 0.2. Again using RICHARDS' formulas, the angle of nip would have to be  $11^\circ$  or under before a bite would occur.

The great variety of shapes and sizes fed to a crusher, as compared with the rather uniform product to the rolls, would indicate that whereas a roll operating with an angle of nip of  $16^\circ$  is just on the danger point, a crusher so operated would have

DEGREE OF REDUCTION AND JAW ANGLE, BLAKE CRUSHERS

Size of crusher, in.	Actual width opening, in.	Length vertical jaw, in.	Set to crush to, in.	Angle between jaws
$4 \times 7$	4	12	$\frac{1}{2}$	$15^\circ 50'$
			1	$13^\circ 45'$
			$1\frac{1}{2}$	$11^\circ 50'$
$7 \times 10$	$6\frac{1}{4}$	$17\frac{1}{2}$	2	$9^\circ 25'$
			1	$16^\circ 30'$
			$1\frac{1}{2}$	$15^\circ 0'$
$9 \times 15$	$8\frac{1}{4}$	24	2	$13^\circ 15'$
			3	$10^\circ 30'$
			$1\frac{1}{2}$	$15^\circ 25'$
$10 \times 20$	$8\frac{1}{2}$	26	$2\frac{1}{2}$	$13^\circ 10'$
			3	$12^\circ 0'$
			4	$9^\circ 30'$
$13 \times 24$	$11\frac{1}{2}$	33	$1\frac{1}{2}$	$14^\circ 40'$
			3	$11^\circ 30'$
			4	$9^\circ 40'$
$15 \times 24$	$13\frac{1}{2}$	33	$1\frac{1}{2}$	$16^\circ 30'$
			3	$14^\circ 15'$
			4	$12^\circ 30'$
			5	$11^\circ 0'$
			$1\frac{1}{2}$	$22^\circ 30'$
			2	$21^\circ 45'$
			3	$20^\circ 30'$
			4	$18^\circ 30'$
			5	$17^\circ 15'$
			6	$15^\circ 20'$
			7	$13^\circ 30'$

exceeded it. From this reasoning it would appear correct that the angles between the jaws of a crusher should not exceed  $12^{\circ}$  to work near its utmost capacity.

By referring to the accompanying table, it is readily seen what degree of reduction under present standard measurements of construction will bring the jaw angle about this limit:

The manufacturers, no doubt, have exceeded this angle, because it gave them the mouth-size that was sought, for the least cost. The direction that has been taken to increase crusher capacity has been to make a wider jaw. It would have been better if the jaw angle had been made smaller, and the additional iron put into the height of the jaw, rather than the width. The second point, the breaking character of the rock, is important, but is a character outside of our control.

It is readily admitted that a decrease in the size of the discharge opening will reduce the capacity. This amount of reduction is, however, greatly underestimated. Extending the principle given by RICHARDS in Vol. I, p. 35, of his "Ore Dressing," we may argue that in a  $15 \times 24$ -in. breaker, if one 15-in. cube reports at the mouth in 125 3-in. cubes, then the capacity at mouth is 125 times that at the throat when breaking to 3 in. If, now, the crushing be reduced to  $1\frac{1}{2}$  in., there would be 1000 cubes produced, and the capacity would be 1000 times greater at the mouth than at the throat. The capacity, then, in the second case would be theoretically but one-eighth of that in the first case.

With the smaller opening there would be a proportionally larger amount of material that would have to be worked on, as with a smaller opening the probability of more stuff being smaller than that opening would be increased. This would have an added effect in reducing the output. As an illustration of how much this capacity reduction is underestimated, apply the principles stated to the catalog capacity of a  $15 \times 24$ -crusher:

COMPARISON OF CAPACITIES  
(Approximate capacity for 24 hours)

Break to .....	3 in.	$2\frac{1}{2}$ in.	2 in.
Tons .....	600	480	420

THEORETICAL

Break to .....	3 in.	$2\frac{1}{2}$ in.	2 in.	$1\frac{1}{2}$ in.
Tons .....	600	347	177	75

An analysis of a catalog table will show the error of basing estimates upon the figures given.

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## APPROXIMATE CAPACITY IN TONS PER DAY OF 10 HOURS

Size	Tons	In.	Tons	In.	Tons	In.	Tons	In.
I—7×10...	50	2	40	1½	25	1	15	¾
II—9×15...	120	2½	100	2	80	1½	60	1
III—11×18	200	3	175	2½	150	2	100	1½

In case I it is seen that a change from 2-in. to 1-in. product gives 0.5 the output; from 1½ to ¾ in., 0.37 the output. In case II, a change from 2 in. to 1 in. gives 0.62 of the output. In case III, a change from 3 in. to 1½ in. gives five-tenths (0.5) the output.

There is no consistency in the table, the intermediate size showing less cut than the one larger and the one smaller. The table is in all probability no more than a guess.

## CRUSHING WITH BLAKE TYPE OF BREAKERS

Abbreviations—C. = solid cast-iron frame; Cap. = capacity; Est. = estimated; griz. = grizzly; HP. = horsepower; h. = hours; In. = inches; L. = lever pattern; Min. = minute; P. = Pitman pattern; p. = per; picked = poor residue left after picking; Rev. = revolutions; S. = sectional bolted frame.

Breaker No.	Pattern	No. used	Mouth size, in.	Rev. per min.	Feed size	Crushed to, in.	Actual cap. per 24 hr., tons	Est. cap. per 24 hr., tons	Run	Repairs per year exclusive of wearing parts	Est. HP.
1	..	1	6×8	450	Mine ore	..	50	125	Dry	..	..
1	P. C.	1	10×13	360	Mine ore	$\frac{3}{4}$	100-120	300	Wet	\$100	..
1	L. C.	1	6×8	500	Mine ore over $1\frac{1}{2}$ in. griz.	1	..	..	..	..	..
1	P. C.	1	10×16	250	Mine ore over 2 in. griz.	2	..	..	..	(c)	20
1	P. C.	1	6×10	350	Mine ore	1	50	150	Dry	..	..
1	L. C.	1	6×9	125	Mine ore	$\frac{3}{4}$	80	200	Wet	..	..
1	P. C.	1	6×9	400	Mine ore picked	$\frac{3}{4}$	37½-40	112-120	Wet	None	4
1	P. C.	1	7×10	320	Mine ore	$\frac{5}{8}$	..	..	..	..	..
1	P. C.	1	9×11	..	Mine ore picked	$1\frac{1}{2}$	95	..	..	..	..
1	P. S.	1	8×10	300	Mine ore over $1\frac{1}{4}$ in. griz.	$1\frac{1}{2}$	..	..	..	..	..
1	P. C.	1	7×10	250	Mine ore	1	100	200	Dry	..	..
1	P. C.	1	9×15	..	Mine ore	$1\frac{1}{2}$	40-50	..	Wet	..	..
1	P. C.	1	9×15	214	Mine ore	$\frac{1}{2}$	100	..	..	..	..
1	L. C.	10	9×15	180	Mine ore	$\frac{1}{2}$	109	140	Wet	\$155	..
1	P. C.	2	9×15	250	Mine ore picked	$1\frac{1}{2}$	90	125	Dry	\$90	7
2	P. C.	1	7×12	250	Mine ore over $1\frac{1}{4}$ in. griz.	$1\frac{1}{2}$	80	150	Wet	\$20	..
1	P. C.	2	8×10	400	Mine ore	$1\frac{1}{2}$	100	..	Dry	..	7
(v)	P. C.	1	9×15	340	Selected shipping ore	$2\frac{1}{2}$	350	..	..	..	..
(b)	P. C.	1	9×15	340	Mine ore picked, over $1\frac{1}{4}$ in. griz.	$2\frac{1}{2}$	..	..	Dry	..	10
									Dry	..	25

CRUSHING WITH BLAKE TYPE OF BREAKERS. *Continued*

Breaker No.	Pattern	No. used	Mouth size, in.	Rev. per min.	Feed size	Crushed to, in.	Actual cap. per 24 h. tons	Est. cap. per 24 h. tons	Run	Repairs per year exclusive of wearing parts	Est. H.P.
1	C	1	7×10	350	Mine ore picked	1½	200	230	Wet	None	7
1	P	2	9×15	280	Mine ore over 1½ in. griz.	1½	250	350	Dry	None	12
1	P	1	7×11	224	Mine ore	.....	75	.....	Wet	.....	.....
1	P	1	7×12	.....	Mine ore over 1½ in. griz.	.....	60	.....	Dry	.....	.....
1	P	1	9×15	.....	Mine ore	.....	.....	.....	.....	.....	.....
1	P	2	10×20	300	Mine ore	.....	300	.....	Dry	.....	.....
2	P	4	7×10	300	(k) On No. 1 trommel 1½ in.	1½	.....	.....	.....	.....	.....
1	P	2	9×15	350	Mine ore	.....	250	.....	Wet	.....	.....
2	P	2	4×10	250	(k) on No. 1 trommel 2½ in.	2½	.....	.....	Wet	.....	.....
2	P	2	9×15	275	Mine ore	.....	300	400	Wet	None	.....
1	P	4	7×10	275	(k) On No. 1 trommel, 20 mm	1	30	100	Wet	None	.....
2	P	1	9×15	250	Mine Ore	.....	300	400	Dry	Small	.....
2	P	1	7×10	250	(k) On No. 1 trommel, ⅜ in.	1	.....	100	Dry	Small	.....
1	P	11	24×36	190	Mine ore, over 3½-in. griz.	12	480	.....	Dry	.....	.....
2	P	11	17×24	200	(k) On No. 2 grizzly 3½ in.	3½	.....	.....	Dry	.....	.....
2	P	2	14×22	84	Mine ore over 4 in. griz.	4	.....	.....	Dry	.....	.....
2	P	2	13×20	140	Mine ore over 4 in. griz.	4	.....	.....	Dry	.....	.....
1	P	3	18×24	84	Mass copper rock (m)	4	.....	.....	Dry	(e)	.....
2	P	9	9×15	129	From No. 1 breaker	5	.....	.....	Dry	.....	.....
3	P	6	13×20	103	Copper rock (m)	2¾	.....	.....	Dry	.....	.....
1	P	9	18×24	132	Mine ore over 4 in. griz.	3	.....	.....	Dry	.....	.....
1	P	4	8×15	216	Mine ore over 4 in. griz.	4	.....	.....	Dry	.....	.....



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### ESTIMATED COST OF <sup>6</sup>CRUSHING BY JAW CRUSHER<sup>1</sup>

Size of mouth in inches .....	4 × 10	7 × 10	9 × 15	10 × 20	13 × 30
Tons crushed in 24 hours.....	84	120	192	300	540
Horsepower .....	5	8	12	20	30
Cost of breaker .....	\$275	\$500	\$750	\$1050	\$2250
Cost, cents per ton, oil.....	0.021	0.021	0.021	0.021	0.021
Cost, cents per ton, interest and depreciation .....	0.106	0.135	0.127	0.114	0.135
Cost, cents per ton, power.....	0.773	0.865	0.811	0.865	0.721
Cost, cents per ton, labor.....	4.762	3.333	2.083	1.333	0.741
Cost, cents per ton, wear .....	0.815	0.815	0.815	0.815	0.815
Cost, cents per ton, repairs.....	0.462	0.462	0.462	0.462	0.462
Total cost, cents per ton.....	6.939	5.631	4.319	3.610	2.895

<sup>1</sup> R. H. RICHARDS, "Ore Dressing," Vol. I.

### ESTIMATED COST OF CRUSHING BY SPINDLE BREAKERS<sup>1</sup>

Screen opening, inches	Per cent. of voids	
	By water displacement	From specific gravity
$\frac{3}{8}$	40.9	46.8
$\frac{3}{8}$	39.6	46.1
$\frac{1}{2}$	42.2	47.1
$\frac{3}{4}$	43.0	45.6
$1\frac{1}{4}$ to $\frac{3}{8}$	45.7	44.7
2 to $\frac{1}{2}$	47.9	46.2
2 to $\frac{3}{4}$	46.6	46.6
$2\frac{1}{4}$ to $\frac{3}{8}$	44.3	42.9
$2\frac{1}{4}$ to $1\frac{1}{4}$	46.2	43.4
3 to 2	46.1	45.1
3 to 2	47.5	46.1

<sup>1</sup> R. H. RICHARDS, "Ore Dressing," Vol. I.

### PER CENT. OF VOIDS IN CRUSHED LIMESTONE<sup>1</sup>

	0	2	4	6	8
Number of breaker.....	4 × 30	6 × 42	8 × 54	11 × 72	18 × 126
Size of mouth in inches.....	72	216	540	1080	3000
Tons crushed in 24 hours.....	3	9	22	45	125
Horsepower.....	\$375	\$760	\$1800	\$3300	\$7000
Cost of breaker.....	0.021	0.021	0.021	0.021	0.021
Cost, cents per ton for oil .....	0.169	0.114	0.108	0.099	0.076
Cost, cents per ton interest and depreciation .....	0.541	0.541	0.541	0.541	0.541
Cost, cents per ton, power.....	5.556	1.852	0.741	0.370	0.133
Cost, cents per ton, wear.....	0.971	0.971	0.971	0.971	0.971
Cost, cents per ton, repairs.....	0.308	0.308	0.308	0.308	0.308
Total cost in cents per ton....	7.556	3.807	2.678	2.310	2.050

<sup>1</sup> RICHARDS, "Ore Dressing," Vol. IV.



An ordinary mine wedge, 8 in. long by 4 in. wide by 2 in. thick at the large end, when caught in  $9 \times 15$ -in. breakers, takes about as long to work through as does a ton of ore. Moral—remove the wood first.

## RELATIVE RESISTANCE TO CRUSHING

Material	Work per unit surface	Work per unit weight
Quartz.....	1.000	1.000
Pyrite.....	.788	.418
Sphalerite.....	.313	.215
Calcite.....	.231	.225
Galena.....	.190	.067

The work performed in crushing quartz is assumed as unity. The figures are not in any units, but are comparative only. The results are from *Bur. of Mines Bull.* 2948.

Symons' Disk Crushers<sup>a</sup>

For the work of secondary breaking from a 3- to 5-in. size, to approximately  $1\frac{1}{2}$  in., the SYMONS' disk crusher is now being largely used, and has been adopted by the larger mining companies such as Phelps, Dodge & Co., the Guggenheim companies, the Anaconda Copper Co., and the Inspiration Copper Co. Records of the Detroit Copper Co. at Morenci, Ariz., give a life of 170,000 tons for one set of manganese-steel disks, which are the main wearing parts, and cost about \$300. The Federal Lead Co., at Flat River, Mo., obtained the low figure of 0.2 ct. per ton for wear over a period of a year.

A test of capacity, power and size of the product of a 48-in. disk crusher was made by DAVID GILMOUR, chief engineer for the Guggenheim Exploration Co., with a view to determining the advisability of using it instead of  $72 \times 20$ -in. rolls, and as a result the disk crusher was adopted for the Chile Copper Co., at Chuquicamata, Chile. One of the tests was as shown herewith:

## Test of Disk Crusher

Feed, 20 per cent. 4 to 6 in., 50 per cent. 2 to 4 in., 25 per cent. 1 to  $1\frac{1}{2}$  in.

Crusher opening,  $1\frac{1}{4}$  in.

Product, 78 per cent,  $\frac{1}{2}$  to  $1\frac{1}{2}$  in., 22 per cent.  $\frac{1}{2}$  in. and smaller.

Capacity, 100 tons per hour.

Power, 29 to 47.9 hp.

It will be noted that the rated capacity for this crusher with  $1\frac{1}{2}$  in. product is 60 to 80 tons; the power from 50 to 65 hp., so that the catalog ratings are conservative.

<sup>1</sup> JULIUS I. WILE, "Tendency of American Milling Machinery Practice," *Eng. and Min. Journ.*, Apr. 17, 1915.

In a more practical way the advantages of the disk crusher can be shown by a comparison of costs, which are available for 1000 ton units for secondary breaking from  $3\frac{1}{2}$  into  $1\frac{1}{2}$  in. The accompanying estimate is based on the cost of power and repairs only, with 8 hr. crushing and power taken at the low figure of \$50 per year, the average yearly tonnage being 350,000 tons. The estimate is given for both class A and class B ores, and comparison is made between gyratories, rolls and disk breakers.

## CRUSHER ACTION ON VARIOUS ORES—CLASS A

	Two No. 5 gyratories, 50 hp. (25 hp. each)	72 × 16-in. rolls, 60 hp.	48-in. disk, 40 hp.
Power.....	0.24 cts.	0.29 cts.	0.2 cts.
Repairs.....	0.65 cts.	0.50 cts.	0.2 cts.
Total....	0.89 cts.	0.79 cts.	0.4 cts.

## CLASS B

	Two No. 6 gyratories, 66 hp. (33 hp. each)	72 × 20-in. rolls, 80 hp.	48-in. disk, 50 hp.
Power.....	0.32 cts.	0.39 cts.	0.25 cts.
Repairs.....	1.30 cts.	1.00 cts.	0.40 cts.
Total....	1.62 cts.	1.39 cts.	0.65 cts.

<sup>1</sup> R. H. RICHARDS, "Ore Dressing," Vol. III.

## Crushing with 'Rolls'

According to PHILIP ARGALL the most successful dry crusher is the belted roll. They do their best work on  $1\frac{1}{2}$ - to 2-in. cubes. In wet crushing they give good results down to 20-mesh and fair down to 40-mesh. According to MR. ARGALL the following formulas give the proper roll speed: Let  $P$  = peripheral speed in feet per minute;  $D$  = diameter of rolls in inches;  $N$  the number of revolutions per minute;  $S$  = size in inches of maximum ore cube fed;  $S_n$  = size in inches of maximum cube fed for a given diameter of roll; then

$$100 \times \frac{\log \frac{16}{s}}{\log 2} = P; 0.0476 \times D - S_n; \frac{382}{D} \times \frac{\log \left( \frac{16}{s} \right)}{\log 2} = N.$$

The angle of nip for a given particle is the angle between the tangents drawn to the rolls at the points where the particle touches. • The most favorable angle is  $32^\circ$ .

• The largest particle which can be fed to a set of rolls, according to HATON DE LA GOUPILLIÈRE is:  $\frac{r}{R} > 18 - 19m$ ; where  $r =$

radius of roll,  $R$  = radius of largest particle in the feed, and  $m$  = ratio between diameter of the largest grain in crushed product and that of the largest grain in the feed.

The theoretical capacity of the rolls is:  $60PWS = C$ ; where

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$P$  = peripheral speed in inches per minute,  $W$  = width of roll face in inches,  $S$  = space between the rolls in inches, and  $C$  = capacity in cubic feet per hour.

#### SIZE OF FEED TO GIVE A 32° ANGLE OF NIP ON DIFFERENT ROLLS

Diameter of rolls in inches	Space between the rolls in inches						
	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	0
36	2.23	2.10	1.96	1.84	1.71	1.57	1.45
30	1.99	1.86	1.73	1.60	1.47	1.34	1.21
26	1.83	1.70	1.56	1.44	1.31	1.17	1.05
24	1.74	1.61	1.48	1.36	1.22	1.10	0.96
20	1.58	1.46	1.32	1.20	1.06	0.94	0.80
16	1.42	1.29	1.16	1.03	0.90	0.77	0.64
9	1.14	1.01	0.88	0.75	0.62	0.49	0.36

#### SIZE OF FEED TO GIVE A 32° ANGLE OF NIP ON DIFFERENT ROLLS

Diameter of rolls in inches	Size of feed to rolls in inches					
	$1\frac{1}{2}$	$1\frac{1}{4}$	1	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{4}$
	Space between rolls (a)					
36	0.46	.....	.....	.....	.....	.....
30	0.280	0.038	.....	.....	.....	.....
26	0.432	0.191	.....	.....	.....	.....
24	0.512	0.270	0.031	.....	.....	.....
20	0.666	0.424	0.185	.....	.....	.....
16	0.822	0.580	0.340	0.101	.....	.....
9	1.193	0.851	0.613	0.372	0.132	.....

(a) Where blank spaces are left the angle of nip is under 32° with the rolls set close together.

**Width of Rolls.**—According to RICHARDS the following are the chief considerations. Wide rolls of the same speed have more surface and hence greater capacity. But as width and capacity increase so do the stresses to be met, and consequently the cost of the machine increases. On the other hand, narrow rolls are much easier to keep true, and by running them faster, provided the speed does not exceed the limits for good work, the capacity lost by narrowing can be regained, the stresses are less, and first cost, weight and friction are reduced.

A table of results of roll crushing, taken from RICHARDS, follows:

GENERAL TABLE OF ROLL DATA

Abbreviations—Bl. = Blake breaker; cap. = capacity; est. = estimated; G. = Gates breaker; gr. = grizzly; h = hours; in. = inches; j m. = jig middlings; L. = Lowry breaker; mag. = magnetic; mac. = maximum; mid. = midlings; ov. = oversize; s. = sectional; th. = through; No. = number; tr. = trommel.

Roll No.	Feed	Product to	Space between rolls, in.	Diameter, in.	Face width, in.	Revolutions per minute	Lat. horse-power required	Cap. per 24 h., tons (a)		Class (r)
								Actual	Max.	
1	From Bl.	Hand jig.	$\frac{3}{4}$	12	14	100	.....	50	130	I
1	Th. Bl., $\frac{3}{4}$ in., on No. 1 tr., $\frac{1}{2}$ in.	No. 1 tr., $\frac{1}{2}$ in.	Close	22	14	22	.....	300	.....	II
2	J. m. th. $\frac{1}{2}$ in.	No. 1 tr., $\frac{1}{2}$ in.	Close	18	14	22	.....	.....	.....	IV
1	Th. Bl., 1 in., on No. 1 tr., 2 mesh.	No. 1 tr., 2 mesh.	Close	26	12	20	.....	.....	.....	II
1	Th. Bl., 1 in.	No. 1 tr., 0.487 in.	$\frac{3}{4}$	22	14	42	.....	40	.....	I
2	J. m., 1 to 0.09 in.	No. 1 tr., 0.487 in.	Close	22	14	.....	.....	.....	.....	IV
1	(b)	No. 1 tr., 0.487 in.	Close	18	14	75	.....	60	70	I, IV
1	(c)	No. 1 tr., 20, 10, 2 mm. (S.)	Close	20	14	90	.....	45	50	II, IV
1	Th. Bl., $1\frac{1}{2}$ in., on No. 1 tr., 0.141 in.	No. 1 tr., 15 mm.	$\frac{1}{4}$	36	14	(d)	.....	100	250	II
1	Th. Bl.	No. 1 tr., 0.083 in.	.....	.....	.....	.....	.....	.....	.....	I
2	Ov. No. 1 tr., 3 mesh	No. 1 tr., 3 mesh.	.....	.....	.....	.....	.....	.....	.....	III
1	Ov. of No. 2 tr., 0.252 in.	No. 2 tr., 0.252 in.	$\frac{1}{4}$	24	12	92 (f)	.....	100	.....	II
2	J. m., 0.252 to 0.060 in.	No. 2 tr., 0.252 in.	$\frac{1}{4}$	24	12	100	.....	80-80	.....	III
3	Th. Bl., 1 in. to 0.060 in.	No. 6 tr., 0.060 in.	Close	16	9	120	.....	.....	.....	IV
1	Th. Bl., 1 in., 0.177 in.	No. 1 tr., 0.177 in.	$\frac{1}{4}$	27	14	80	10	9	.....	I
2	Ov. No. 1 tr., 0.177 in.	No. 1 tr., 0.177 in.	Close	24	14	80	10	25	.....	III
1	Th. Krom breaker, 1 in.	No. 1 tr., 12 mm.	0.4	30	16	28 (h)	20	.....	.....	I
2	Th. Blake., $1\frac{1}{2}$ in.	No. 1 tr., 12 mm.	Close	30	16	40	20	.....	.....	III, IV
1	(g)	No. 1 tr., 7 mm.	.....	27	14	.....	.....	100	.....	I
2	(h)	No. 1 tr., 7 mm.	Close	27	14	.....	.....	100	.....	III, IV
1	Th. Bl., $\frac{1}{2}$ in., on No. 1 tr., 10 mm.	No. 1 tr., 10 mm.	$\frac{1}{4}$ to $\frac{1}{2}$	28 $\frac{1}{2}$	12	24	.....	75	100	I
2	Ov. No. 2 tr., 7 mm.; J. m., 10 to 0 mm.	No. 2 tr., 7 mm.	$\frac{1}{4}$ to $\frac{3}{16}$	30	12	24	.....	142	190	III, IV
1	Th. Bl., $1\frac{1}{2}$ in.; Ov. No. 1 tr., 6 mm.	No. 1 tr., 6 mm.	Close	30	14	8 $\frac{1}{4}$	8	105	125	I



GENERAL TABLE OF ROLL DATA. *Continued*

Roll No.	Feed	Product to	Space between rolls, in.	Diameter, in.	Face width, in.	Revolutions per minute	Est. horse-power required	Cap. per 14 h. tons (a)		Class (c)
								Actual	Max.	
1	J.m., 0.31 in. to 0	No. 3 tr., 0.2 in.	.....	20	10	...	...	...	...	IV
3	Th. G., 1½ in.; Ov. No. 1 tr., 25 mm.	No. 1 tr., 25 mm.	¾	26	15	40	...	...	...	II
2	J.m., 25 to 20 mm.	No. 1 tr., 25 mm.	½	26	15	47	...	...	...	IV
3	J.m., 20 to 3 mm.	No. 1 tr., 25 mm.	¾	20	12	37	...	...	...	IV
4	J.m., 10 to 3 mm.; ov. No. 7 tr., 7 mm.	No. 7 tr., 7, 3 mm. (S.)	½	42	12	42	...	...	...	IV
1	J.m., 1¼ to ¾ in.	No. 2 tr., ¾ in.	½	26	15	60	...	...	...	IV
2	J.m., ¾ to ¾ in.	No. 2 tr., ¾ in.	¾	26	15	60	...	...	...	IV
3	J.m., ¾ to ¾ in. (n)	No. 6 tr., 2¼ mm.	Close	26	15	60	...	...	...	IV
1	Jig tailings, 15 to 8¼ mm.	No. 2 tr., 1½ in., 15 mm. (S.)	¾	30	16	38	...	...	...	IV
2	From No. 2 Bl., 1 in.	No. 2 tr., 1½ in., 15 mm. (S.)	Close	26	15	40	...	...	...	IV
3	J.m., 20 to 7 mm.	No. 1 tr., 20 mm.	¾	30	16	31	...	50	75	I
4	J.m., 7 to 3 mm.; J.m., 3 to 0 mm.	No. 1 tr., 20 mm.	Close	30	16	31	...	75	120	IV
1	Th. No. 2 breaker.	No. 5 tr., 3 mm.	Close	30	15	16	...	120	120	IV
2	From No. 1 rolls.	No. 2 rolls.	.....	30	15	24	...	...	...	III
3	J.m., ¾ to ¾ in.	No. 1 tr., ¾ in.	Close	30	15	24	...	...	...	IV
4	J.m., ¾ to ¾ in.; ov. No. 5 tr., ¼ in.	No. 2 tr., ¾ in.	Close	30	15	...	...	...	...	IV
5	J.m., th. ¼ in.	No. 5 tr., ¼ in.	Close	30	15	...	...	...	...	IV
1	J.m., ¼ in. to 0; ov. No. 5 tr., 0.1 in.	No. 5 tr., 0.1 in.	Close	22	16	50	10	...	125	IV
1	J.m., 1 in. to 3 mm.; ov. No. 2 tr., 3 mm.	No. 2 tr., 3 mm.	Close	30	16	60	...	65	100	IV
1	Th. Bl. 1½ in., on No. 1 tr., 4 mesh	No. 1 tr., 4 mesh	.....	20	16	...	...	...	...	II
2	Th. Bl., 1½ in.	No. 1 tr., 0.224 in.	¾	27	14	23	...	75	...	I
2	Ov. No. 1 tr., 0.224 in.	No. 1 tr., 0.224 in.	Close	20	10	30	...	...	...	III

1	Th. Bl., 1½ in.	No. 1 tr., 3 and 4 mesh.	¾	36	14	40	100	125	I
2	Ov. of No. 1 tr., 3 and 4 mesh.	No. 1 tr., 3 and 4 mesh.	Close	36	14	37½	60	100	III
1	Th. Bl., 1½ in.	No. 1 tr., 3 mesh.	½	27	14	40	75	.....	I
2	Ov. of No. 1 tr., 3 mesh.	No. 1 tr., 3 mesh.	Close	27	14	.....	.....	.....	III
1	Th. L., ¾ in.; th. No. 1 tr., 1 in.	No. 2 tr., ½ in.	Close	30	18	90	.....	.....	I
2	Ov. No. 2 tr., 1 to ½ in.	No. 2 tr., ½ in.	Close	30	18	100	.....	.....	III
3	Mid. of mag. separator, ½ in. to 0	No. 2 tr., ½ in.	Close	30	18	100	.....	.....	IV
1	From Buchanan fine breaker, 1 in.	No. 2 rolls.	½ to ¾	24	14	100	60	.....	I
2	From No. 1 rolls.	No. 2 tr. (p)	Close	18	12	130	60	.....	III
1	Th. Bl., ¾ in., on No. 2 tr., ¼ in.	No. 3 tr., 0.060 in.	Close	30	15	34	90	120	II
2	Th. No. 2 tr., ¼ in., on No. 3 tr., 0.060 in.	No. 4 tr., 0.058 in.	Close	24	16	130	25	40	II
3	Th. No. 9 tr., ¼ in., on No. 4 tr., 0.058 in.	No. 4 tr., 0.058 in.	Close	24	16	130	25	40	II
1	Th. Bl., 1½ in.	Log washer.	¾	30	14	25	80	190	I
2	(g)	No. 1 tr., 6 mm.	¾	24	12	30	10	.....	III

(a) Actual capacity is what the rolls actually do in 24 hours; maximum capacity is what it is estimated they would do if run at their maximum capacity. (b) Th. Bl., 20 mm.; No. 1 jig tailings, 20 to 10 mm.; No. 2 j.m., 10 to 2 mm. (c) Th. No. 1 tr., 15 in., on No. 2 tr., 10 mm.; j.m., 10 to 0 mm. (d) One roll makes 44 revolutions, the other 45. (e) Th. gr., 112 in., and Bl., 112 in., on No. 1 tr., 0.252 in. (f) 102 revolutions per minute caused excessive wear. (g) 40 tons for hard ore, 60 for soft. (h) At 35 revolutions the rolls became glazed. (i) Ov. No. 1 tr., 12 mm.; j.m., 12 to 3 mm.; j.m., 3 to 0 mm. (j) This is the result of actual measuring settling table heads. (k) Ov. No. 1 tr., 7 mm.; jig tailings, 7 to 3 mm.; j.m., 3 to 0 mm. (l) Th. Donez, 114 in., on No. 1 tr., 40 mm.; ov. No. 2 tr., 16 mm.; jig tailings, 40 to 60 mm. (m) j.m., 25 mm. to sand; ov. No. 5 tr., 212 mm. (n) Jig middlings, 38 in. to 212 mm.; ov. No. 6 tr., 212 mm. (o) Jig tailings, 112 in. to 15 mesh; ob. No. 2 tr., 112 in. (p) This varies from 14 in. down to 20 mesh. (q) Ov. No. 1 tr., 6 mm., which treats No. 1 roll stuff. (r) The roll classes referred to in the above table, I, II, III, IV are: I. Rolls which crush the product of a breaker; II. Rolls which crush the product of a breaker after it has gone through a trommel; III. Rolls which crush the product of a previous pair of rolls. This may or may not have been screened; IV. Rolls that are crushing jig middlings.

# 450 METALLURGISTS AND CHEMISTS' HANDBOOK

## Tube Mill Data<sup>1</sup>

Relation between Per Cent. Ore and Solution, Fineness of Grinding and Horsepower

SCREEN ANALYSIS OF SAND FED TO TUBE MILLS, 12 FT. LONG, 5 FT. DIAMETER

On 20	On 30	On 40	On 60	On 80
6 0	20.0	24.0	23.0	11 0
On 100	On 120	On 150	Through 150	
8.0	4.0	2.0	2.0	

## VARIABLE PEBBLE VOLUME, FIXED ORE AND SOLUTION

Pounds, pebbles	On 60	On 100	On 150	Through 150	Per cent., ore	Per cent., solution	Tons ore per 24 hr.	Indicated horsepower
3,000	42.5	27.5	8.0	22.0	63.72	36.28	172	18.80
6,000	46.5	23.5	8.0	22.0	70.17	29.83	172	20.37
9,000	42.0	26.0	8.0	24.0	74.29	25.71	172	22.5
12,000	32.0	32.0	12.0	24.0	60.00	40.00	172	32.16
15,000	29.0	30.0	14.0	27.0	65.38	34.62	172	39.13
16,800	18.0	36.0	12.0	34.0	66.67	33.33	172	42.88
18,000	3.5	29.0	16.0	51.5	66.67	33.33	172	47.16
19,000	4.0	28.0	13.0	55.0	66.67	33.33	172	51.45
20,000	9.0	32.0	15.0	44.0	71.88	28.12	172	56.28
21,000	6.0	30.0	13.5	50.5	71.88	28.12	172	60.10
22,000	6.0	29.0	15.0	50.0	71.88	28.12	172	65.39
23,000	6.0	30.0	14.0	50.0	70.37	29.63	172	77.18
24,000	3.0	27.0	16.0	54.0	70.96	29.04	172	68.61
24,500	4.0	26.0	13.0	57.0	68.18	31.82	172	69.68
25,000	3.0	26.0	14.0	57.0	66.67	33.33	172	75.04
26,000	5.0	28.0	15.0	52.0	70.00	30.00	172	68.60
27,000	8.0	33.0	14.0	45.0	68.00	32.00	172	64.85

## VARIABLE ORE AND SOLUTION, FIXED PEBBLE VOLUME

Pounds, pebbles	Feed, inches	Tons ore per 24 hr.	On 60	On 100	On 150	Through 150	Per cent., ore	Per cent., solution	Indicated horsepower
20,000	3	172	7.0	32.0	13.0	48.0	64.71	35.29	56.4
20,000	3	172	13.0	35.0	11.0	41.0	66.67	33.33	54.28
20,000	3½	190	12.5	36.0	10.0	41.5	71.05	28.95	51.6
20,000	3½	190	14.0	34.0	12.0	40.0	67.86	32.14	54.8
20,000	4	216	16.0	34.0	14.0	36.0	68.18	31.82	53.2
20,000	4	216	14.0	36.0	16.0	34.0	69.70	30.30	49.4
20,000	4½	231	26.0	38.0	11.0	30.0	66.67	33.33	47.5
20,000	4½	231	30.0	30.0	10.0	30.0	72.22	27.78	43.5

<sup>1</sup> HOFMAN, "General Metallurgy."



## VARIABLE SOLUTION, FIXED PEBBLE VOLUME AND ORE FEED

Pounds, pebble	Ore feed, inches	Tons ore per 24 hr.	Tons solution per 24 hr.	On 60	On 100	On 150	Through 150	Per cent., ore	Per cent., solution	Indicated horse-power
20,000	3	172	68.0	12.5	36.0	10.0	41.5	71.43	28.57	45.0
20,000	3	172	75.0	13.0	34.0	12.0	41.0	69.56	30.44	48.9
20,000	3	172	90.0	8.0	30.0	13.0	49.0	65.67	34.33	55.8
20,000	3	172	92.0	8.0	32.0	14.0	46.0	65.20	34.80	57.4
20,000	3	172	98.0	9.0	33.0	12.0	46.0	63.78	36.22	58.0
20,000	3	172	111.0	8.0	33.0	13.0	46.0	60.70	39.30	56.9
20,000	3	172	113.0	7.0	31.0	13.0	50.0	60.44	39.56	55.0
20,000	3	172	136.0	8.0	34.0	12.0	46.0	55.71	44.29	55.8
20,000	3	172	196.0	7.0	32.0	14.0	47.0	47.10	52.90	59.0
20,000	3	172	207.0	5.5	30.5	13.0	51.0	45.40	54.60	62.3
20,000	3	172	268.0	8.0	32.0	12.0	48.0	38.90	61.10	62.3

WORK OF GRINDING PAN AND TUBE MILL AT HOMESTAKE<sup>1</sup>

	5-ft. grinding pans, 12,308 tons ground by 7 pans	5 X 14-ft. tube mill	
		Regular adjustment, medium feed	Special adjustment, heavy feed
Total tons ground per day	19.34 per pan	73	110.0
Tons ground per day to pass 200-mesh sieve	10.83 per pan	43	52.8
Water in feed, per cent	80-90	38	38.4

	Head	Tails	Head	Tails	Head	Tails
Assay: gold value per ton	\$2.66*	\$2.07	\$2.49	\$2.04	\$2.49	\$2.04
Sizing test: per cent. on 50 mesh. . . . .	47	6.0	39.0	5.0	18.0	7.0
Through 50; on 80 . . . .	34	14.0	38.0	12.0	49.0	15.0
Through 80, on 100 . . . .	9	14.0	12.0	13.0	17.0	14.0
Through 100; on 200. . . .	6	26.0	7.0	28.0	11.0	26.0
Through 200. . . . .	4	40.0	4.0	42.0	5.0	38.0
Tons ground per horse-power per day at one passage through grinder. . . . .		2.30		1.94		2.92
To pass 100-mesh sieve. . . . .		1.31		1.14		1.40
To pass 200-mesh sieve. . . . .		0.83		0.74		0.97

Material consumed. } Iron, worn, 3.41 Pebbles, 1.66 Pebbles, 1.30  
pounds per ton } Iron, scrapped 0.82  
Total iron 4.23

<sup>1</sup> HOFFMAN, "General Metallurgy."

LANE LOW-SPEED CHILEAN MILL DATA<sup>1</sup>

Size of mill	Type of ore	Size of feed	Discharge	Consistency of overflow	Tons per 10 hrs.
10-ft.	Schist and hard quartz.....	1-in. ring size.	7½-in. overflow, no screen .....	80 % water	19.4
10-ft.	Same ore as above.....	1-in. ring size.	6-in. overflow, 30-mesh screen....	80 % water	13.3
10-ft.	Hard, no talcose matter.....	¾-in. ....	7½-in. overflow .....	.....	16.6
10-ft.	Tough, close-grained quartz.....	¾-in. ....	7-in. overflow .....	.....	13.3
10-ft.	Chunderlee, Australia.....	1½-in. ....	7-in. overflow .....	.....	16.6
10-ft.	Chunderlee, Australia.....	1½-in. ....	9-in. overflow .....	.....	16.6
10-ft.	Hard quartz.....	.....	8½-in. overflow .....	82-84 %	20-21
7-ft.	Brecciated quartz and andesite.	.....	10-in. overflow .....	80 % water	.....

Size of mill	Screen analysis (not cumulative)					Rev. per min.	Remarks
	+30	+40	+60	+80	+100	+120	
10-ft.	0.428	0.858	2.376	5.346	13.848	3 656 73.182	.....
10-ft.	none	none	0.87	3.959	13.07	5.952 76.049	.....
10-ft.	0.16	1.05	6.33	4.06	15.33	.....	Shows screen is a detriment 6.84 % on 150; 12.25 % on 200, 53.42 through 200
10-ft.	.....	2.7	12.0	12.0	11.8	61.5	.....
10-ft.	.....	1.0	2.0	3.0	4.0	90.0	} To compare effect of height of discharge Barnes-King Development Co., Mont. Argonaut mine, Cal. 62 % minus = 200
10-ft.	.....	0.5	2.25	1.5	3.5	92.75	
10-ft.	.....	3.0	12.0	11.0	13.0	61.0	
7-ft.	.....	.....	.....	3.4	12.5	.....	.....

<sup>1</sup> From original notes of ALEXANDER McLAREN, Litchfield, Conn.

Mr. McLaren says that at least 2 in. of pulp should be kept under the rollers of the slow-speed LANE mill. The slow-speed machine produces a large amount of fine material, but it is not a good regrounding machine.

CRUSHING IN HIGH-SPEED CHILEAN MILLS<sup>1</sup>

Mill	Type	Rev. per. min.	Capacity 24 hr.	Screen mesh	Feed	Ore	Size of product					
							+30	+50	+60	+100	+150	+200
Portland.....	Akron 6-ft..	34	124	30	¾-in.	Hard.....	.....	21	.....	12.0	5	6.0
Independence...	Akron 6-ft..	33	120	30	¾-in.	Hard.....	.....	.....	.....	.....	.....	62.0
Goldfield.....	Trent 6-ft..	32	75	30	4-mesh	Medium....	4.0	10	.....	25.0	6	6.0
Mogul.....	Monsadnock.	.....	105	30	1½-in..	Hard.....	14.5	.....	17.8	12.6	.....	15.7
												39.4

One horsepower will crush from 1 to 2¼ tons of ore in the slow-speed mill.

<sup>1</sup> Private notes of H. A. McGraw.

## CRUSHING WITH GYRATORY CRUSHERS

Abbreviations.—Br. = breakers; c. = comet; cap. = capacity; est. = estimated; g. = Gates; griz. = grizzly; hp. = horsepower; in. = inches; L. = Lowry; max. = maximum; No. = number.

Baker No.	Pat-tern used	No. used	Size	Revolutions per minute		Size of feed	Size crushed to inches	Actual cap. per 24 hours, tons	Est. max. cap. per 24 hours, tons	Repairs besides wearing parts	Est. hp. required	Head raised by
				Of pulley	Of head							
1	C	1	D	320	160	Mine ore.....	2½	200	(b) 960	(c)	(d) 30	Worm gear.
1	C	1	4	340	170	Mine ore over 1½-in. griz.	2½	250	960	(e)	20-25	.....
1	G	2	3	425	212	Mine ore over 1½-in. griz.	1½	110	.....	.....	.....	.....
1	G	1	3	500	250	Mine ore over 1-in. griz.	1	200	480	.....	20	.....
1	C	1	6	.....	.....	Mine ore over 1½-in. griz.	2	75	.....	.....	.....	.....
1	G	1	3	.....	.....	Mine ore.....	2	17	.....	.....	.....	.....
1	G	1	3	425	212	Mine ore over ¾-in. griz.	1	125	380	(g)	12	Screw to 6 in.
1	G	2	6	.....	.....	Mine ore.....	1½	200	.....	.....	.....	Screw to 6 in.
1	C	3	D	.....	.....	Mine ore.....	1 to 1½	60	.....	.....	.....	Shims up to 6 in.
1	C	1	D	400	200	Mine ore over 1½-in. griz.	3	100	.....	(h)	40	Worm gear.
4	L	1	.....	.....	.....	Mine ore over (i)	¾	.....	.....	.....	.....	.....

\* (a) These are estimates by the mill managers; for capacities quoted by manufacturers, see Tables 19 and 20. (b) This can probably crush 1440 tons in 24 hours. (c) Repairs, oil and other incidentals, \$200 per year. (d) This is the result of actual measurement. (e) None except occasional babbitt. (f) Babbitt eccentric every 6 months. (g) Bevel gear and pinion gear. (h) Babbitt bearings. (i) Through No. 3 breaker on No. 1 trommel, 1 in.

## HARDINGE MILL DATA

No.	Diameter of mill, feet	Length of cylinder, inches	Type	Mining company	Gangue	Material	Charge, balls or pebbles, pounds	Speed, per min. rev.
122	4.5	13	Ball	Vipond Porcupine Mines Co.	Quartz and basalt	Ore from mill bin	4,000	33
107	6*	16	Ball	Miami Copper Co.	Sliceous porphyry	Ore from mill bin	8,000	28
155 <sup>a</sup>	6	16	Ball	Britanna M. & S. Co.	Quartzose, very hard	Jig tailing	8,200	28
192	6	16	Ball	McIntyre Porcupine Mines	Quartz and schist	Rock-crusher product	8,000	28
156	6	16	Ball	McIntyre Porcupine Mines	Quartz and schist	Rock-crusher product	8,000	28
191	6	16	Ball	Buckhorn Mines Co.	Decomposed porphyry and basalt	Rock-crusher product	8,000	28
121	6	22	Pebble	Bunker Hill & Sullivan	Quartzite and siderite	Middling from jigs and tables	4,000 (†)	32
113	6	72	Pebble	Vipond Porcupine Mines	Quartz and basalt	Oversize Colbath classifier	9,000	27
108	8	22	Pebble	Miami Copper Co.	Altered schist	Product 16 by 42-in. rolls	10,000	27
80	8	22	Pebble	Miami Copper Co.	Altered schist	Product 16 by 42-in. rolls	10,000	27
109	8	22	Pebble	Federal M. & S. Co.	Quartzite and siderite	Jig middling	10,000	28
75	8	22	Pebble	Federal M. & S. Co.	Quartzite and siderite	Coarse Wilfley middling	10,000	28
136	8	22	Pebble	Federal M. & S. Co.	Quartzite and siderite	Jig middling	10,000	28
150	8	22	Pebble	Vieille Montagne Zinc Co.	Sliceous limestone	Jig middling	6,000	29.5
34	8	22	Pebble	Calumet & Hecla	Conglomerate	Jig tailing	6,000	27
33	8	30	Pebble	Copper Range Consol.	Amygdaloid	Jig tailing	10,000	28
142	8*	36	Pebble	Arizona Copper Co.	Porphyry	Screened roll product	10,500	29
135	7	144	Tube	Federal M. & S. Co.	Quartzite	Wilfley middling	18,000	22.25

\* Mill overload.

<sup>a</sup> Note R.M.E.

b — 100 mesh, c — 150 mesh.

HARDINGE MILL DATA. Continued

No.	Tons, per 24 hr.	Horsepower	Tons per horsepower	Feed		Energy units	Discharge		Per cent. -200 mesh	Energy units	Difference, E.U.	Relative mech. eff. (R.M.E.)	Per cent. water in feed	Elevation of feed end, inches	Pebbles or balls, pounds per ton
				All pass, mm.	Average size, mm.		All pass, mm.	Average size, mm.							
122	48	16	3	30.8	12.01	280.2	6.3	0.26	40.2%	1,423.4	1,143.2	34.3	50	2	0.578
107	351	35	10	38.1	6.01	665.3	12.7	0.86	21.8	1,247.0	581.7	58.3	50	0	0.72
155*	251	39	6.4	6.35	1.28	912.5	6.35	0.24	34.2%	1,432.7	520.2	33.5	40	0	0.5
192	150	36	4.2	50.8	12.7	313.1	6.35	0.19	41.07	1,705.1(?)	1,392.0	58.0	50	1.25	0.5
156	150	36	4.2	50.8	10.04	182.3	1.65	0.25	37.2	1,330.0	1,147.5	47.8	60	1.25	0.45
191	160	33	4.8	38.1	7.09	525.4	3.2	0.16	28.0	1,535.6	1,010.2	48.6	80	1.5	0.5
121	60.3	16(?)	5.2	3.0	0.58	1,092.8(?)	0.36	0.09	41.8	1,686.9	594.1	30.9	75(?)	0.5	0.5
113	40	30	1.3	3.0(?)	0.65	1,134.6	0.24	0.05	68.8	1,823.4	668.8	9.19	50	0.0	0.5
108	101	36	2.8	25.4	1.36	973.8	1.65	0.19	35.9	1,573.2	599.4	16.8	63	1.5	0.5
80	180	36	5.0	12.7	1.1	990.3	1.65	0.17	38.1	1,591.3	601.0	30.0	62.5	1.5	0.5
109	112.5	35.8	3.1	4.7	1.12	943.2	1.65	0.14	25.0	1,594.7	651.5	20.5	60	0.0	2.0
75	99	36	2.8	5.0	0.55	1,640.9	0.83	0.09	67.0	1,750.6	709.7	20.0	55	0.0	1.5-2
136	111.5	35.3	3.3	4.7	0.99	986.4	0.83	0.12	39.0	1,649.4	663.0	21.7	71.8	2.0	2.0
150	120	35(?)	3.4	12.7	3.15	632.5	2.4	0.21	13.5	1,492.3	859.8	29.5	.....	4.0	0.5
34	42.5	35.5	1.2	6.35	0.56	1,195.6	1.65	0.08	40.8	1,614.7(?)	419.1	5.0	40	0.0	2.0
34	65	46(?)	1.4	6.35	1.72	825.8	0.83	0.10	34.0	1,652.9	827.1	11.7	64	1.0	2.5
142	208	55	3.8	12.7	2.89	786.5	2.36	0.27	34.7	1,592.1	715.6	27.1	59	0.0	2.4
135	124	86	1.4	2.3	0.41	1,051.4	0.83	0.11	44.5	1,690.2	638.8	9.2	58.8	0.0	4-5

\* The "energy units" are calculated on STADLER'S rules (cf. "Eng. and Min. Journ.," Nov. 21 and 28, 1914). See for another basis ARTHUR GATES on the "Crushing-Surface Diagram," May 24, 1913, and Apr. 18, 1914, and the "Work of Crushing," by ARTHUR F. TAGGART, "Trans. A. I. M. E.," February, 1914. Either method gives comparative results, one must be wrong in absolute units, and the arguments are too voluminous to reprint here.

HARDINGE MILL DATA<sup>1</sup>

	6 ft. by 16-in. ball mill	8 ft. by 22-in. pebble mill
Average maximum size of feed, mm. ....	44.5	9.7
Average size of feed, mm. ....	9.0	1.26
Average maximum size of product, mm. ....	6.0	1.5
Average size of product, mm. ....	0.37	0.14
Average per cent. of -200 mesh in product. ....	28.9 <sup>2</sup>	37.0
Average per cent. of -200 mesh in product, no slope. ....		44.3
Average per cent. of -200 mesh in product, 0.5 to 4 in. slope. ....		31.6
Reduction ratio, range. ....	7 to 67	6 to 15
Reduction ratio, average. ....	39.6	8
Average size of product, no slope, mm. ....		0.10
Average size of product, slope 0.5 to 4 in. ....		0.17
Average tonnage. ....	203	110
Average tonnage at no slope. ....		85
Average tonnage at 0.5 to 4 in. slope. ....		128
Average horsepower. ....	35.06	35.6
Average charge, balls or pebbles, tons. ....	4	4.5
Average ball or pebble consumption, pounds per ton. ....	0.51	1.94
Average relative mechanical efficiency. ....	53.2	20.5
Average percentage of water in feed. ....	60	58.7
Average revolutions per minute. ....	28	27.8

<sup>1</sup> *Trans. A. I. M. E.*, July, 1915.<sup>2</sup> Nos. 155 and 191 estimated.

## Stamp Milling

Stamp order—Homestake 1 4 2 5 3

Stamp order—Brazil 1 5 2 4 3

Drops per minute—theoretical maximum on 9-in. drop—95.

Drops per minute—theoretical maximum on 8-in. drop—100 to 108.

STAMP MILL DROPS<sup>2</sup>

Length of drop, inches	Number of drops per minute	Total inches drop per minute	Compara- tive power required	Number units crushing force per drop	Number units crushing force per minute
6	115	690	100.00	1.0000	115.00
7	108	756	109.57	1.1667	126.00
8½	100	850	123.19	1.4167	141.67
10½	90	945	136.96	1.7500	157.50

<sup>2</sup> MCFARREN'S. "Stamp Milling and Amalgamation." Courtesy of the "Mining and Scientific Press."

# **HORSEPOWER PER STAMP REQUIRED BY THE 5-STAMP BATTERY<sup>1</sup>**

**Height of Drop in Inches and Number of Drops per Minute**

## **A. NOMINAL HORSEPOWER TO RAISE STAMPS WITHOUT FRICTION**

Weight of stamp in pounds	5 in. 115 drops	6 in. 110 drops	7 in. 105 drops	8 in. 100 drops	9 in. 95 drops	10 in. 90 drops
850	1.234	1.417	1.578	1.717	1.835	1.932
900	1.307	1.500	1.670	1.818	1.943	2.045
950	1.379	1.584	1.764	1.919	2.052	2.159
1000	1.452	1.667	1.856	2.020	2.159	2.273
1050	1.525	1.750	1.949	2.121	2.267	2.386
1100	1.597	1.833	2.042	2.222	2.375	2.500
1150	1.670	1.917	2.134	2.323	2.483	2.614
1200	1.742	2.000	2.227	2.424	2.591	2.727
1250	1.815	2.083	2.320	2.525	2.699	2.841
1300	1.888	2.167	2.413	2.626	2.807	2.955
1350	1.960	2.250	2.506	2.727	2.915	3.068
1400	2.033	2.333	2.598	2.828	3.023	3.182
1450	2.105	2.417	2.691	2.929	3.131	3.295
1500	2.178	2.500	2.784	3.030	3.239	3.409
1550	2.251	2.583	2.877	3.131	3.347	3.523
1600	2.323	2.667	2.970	3.232	3.455	3.636
1650	2.396	2.750	3.062	3.333	3.563	3.750
1700	2.468	2.833	3.155	3.434	3.670	3.864
1750	2.541	2.917	3.248	3.535	3.778	3.977
1800	2.614	3.000	3.341	3.636	3.886	4.091
1850	2.686	3.083	3.434	3.737	3.994	4.204*
1900	2.759	3.167	3.527	3.838	4.102	4.318
1950	2.831	3.250	3.619	3.939	4.210	4.432
2000	2.904	3.333	3.712	4.040	4.318	4.545
2050	2.978	3.417	3.805	4.141	4.426	4.659
2100	3.050	3.500	3.898	4.242	4.533	4.772
2150	3.123	3.583	3.990	4.343	4.641	4.886
2200	3.194	3.666	4.084	4.444	4.750	5.000

<sup>1</sup> McFARREN's "Stamp Milling and Amalgamation." If the number of drops used varies from that in the table, multiply the horsepower taken from the table by the number of drops used, and divide by the number of drops in the table.

**B. HORSEPOWER APPLIED TO CAM-SHAFT PULLEY**  
(1.202 times A)

Weight of stamp in pounds	5 in. 115 drops	6 in. 110 drops	7 in. 105 drops	8 in. 100 drops	9 in. 95 drops	10 in. 90 drops
850	1.483	1.703	1.897	2.064	2.206	2.322
900	1.571	1.803	2.008	2.185	2.336	2.459
950	1.658	1.903	2.119	2.307	2.465	2.595
1000	1.745	2.003	2.231	2.428	2.595	2.732
1050	1.833	2.103	2.343	2.550	2.725	2.868
1100	1.920	2.204	2.454	2.671	2.855	3.005
1150	2.007	2.304	2.566	2.793	2.984	3.142
1200	2.094	2.404	2.677	2.914	3.114	3.278
1250	2.182	2.504	2.789	3.035	3.244	3.415
1300	2.269	2.604	2.900	3.157	3.374	3.551
1350	2.357	2.704	3.012	3.278	3.504	3.688
1400	2.444	2.805	3.123	3.400	3.633	3.825
1450	2.532	2.905	3.235	3.521	3.763	3.961
1500	2.619	3.005	3.347	3.642	3.893	4.098
1550	2.706	3.105	3.458	3.764	4.023	4.234
1600	2.793	3.205	3.570	3.885	4.152	4.371
1650	2.881	3.305	3.681	4.007	4.282	4.507
1700	2.968	3.406	3.793	4.128	4.412	4.644
1750	3.055	3.506	3.904	4.250	4.542	4.781
1800	3.143	3.606	4.016	4.371	4.671	4.917
1850	3.230	3.706	4.127	4.492	4.801	5.054
1900	3.317	3.806	4.239	4.614	4.931	5.190
1950	3.404	3.906	4.350	4.735	5.061	5.327
2000	3.492	4.007	4.462	4.857	5.190	5.464
2050	3.579	4.107	4.574	4.978	5.320	5.600
2100	3.667	4.207	4.685	5.099	5.450	5.737
2150	3.754	4.307	4.797	5.221	5.580	5.873
2200	3.840	4.408	4.908	5.342	5.710	6.010



**C. APPROXIMATE TOTAL HORSEPOWER**  
(1.35 times A)

Weight of stamp in pounds	5 in. 115 drops	6 in. 110 drops	7 in. 105 drops	8 in. 100 drops	9 in. 95 drops	10 in. 90 drops
850	1.666	1.913	2.130	2.318	2.477	2.608
900	1.764	2.025	2.255	2.454	2.623	2.762
950	1.862	2.138	2.380	2.591	2.769	2.915
1000	1.960	2.250	2.506	2.727	2.915	3.069
1050	2.058	2.363	2.631	2.863	3.060	3.222
1100	2.156	2.475	2.756	3.000	3.206	3.375
1150	2.254	2.588	2.881	3.136	3.352	3.529
1200	2.352	2.700	3.007	3.272	3.498	3.682
1250	2.450	2.813	3.132	3.409	3.643	3.836
1300	2.548	2.925	3.257	3.545	3.789	3.989
1350	2.646	3.038	3.383	3.681	3.935	4.143
1400	2.744	3.150	3.508	3.818	4.081	4.296
1450	2.842	3.263	3.633	3.954	4.226	4.449
1500	2.940	3.375	3.758	4.091	4.372	4.603
1550	3.038	3.488	3.884	4.227	4.518	4.756
1600	3.136	3.600	4.009	4.363	4.663	4.910
1650	3.234	3.713	4.134	4.500	4.809	5.063
1700	3.332	3.825	4.260	4.636	4.955	5.217
1750	3.430	3.938	4.385	4.772	5.101	5.370
1800	3.528	4.050	4.510	4.909	5.246	5.523
1850	3.626	4.163	4.635	5.045	5.392	5.677
1900	3.724	4.275	4.761	5.181	5.538	5.830
1950	3.822	4.388	4.886	5.318	5.684	5.984
2000	3.920	4.500	5.011	5.454	5.829	6.137
2050	4.018	4.613	5.136	5.590	5.975	6.291
2100	4.116	4.725	5.262	5.727	6.121	6.444
2150	4.214	4.838	5.387	5.863	6.266	6.597
2200	4.312	4.950	5.512	6.000	6.412	6.750

**Mud Sills.**—These vary from three to four and range from 12 × 12 to 24 × 24 in. These are used only with old-style wooden foundations.

**Cross Sills.**—These range from 12 × 16 in. to 20 × 24 in.

MORTAR BLOCKS<sup>1</sup>

Depth		Length		Width		Foundation	Material	How fastened
Ft.	In.	Ft.	In.	Ft.	In.			
12	0	.....	.....	2	8	.....	2-in. plank on end (a)	.....
9	0	4	10	2	4	Solid rock	2-in. planks	By wire spikes.
14	0	4	10½	2	6	Concrete (b)	30 × 30-in. timbers	.....
12	0	5	0	2	6	Solid rock	.....	.....
12	9	5	0	2	6	Solid rock	30 × 30-in. timbers	By 1-in. bolts.
14	0	4	10	2	6	Solid rock	28 × 30-in. timbers	.....
19	0	4	8	2	2	Solid rock	2 × 12-in. plank	By 30-penny spikes.
18	0	(c) 28	4	2	6	Solid rock	Spruce 6 × 2-in. and 12 × 2 (d)	By 5-in. spikes.
9	2	4	7	2	4	.....	Three timbers	.....
10	0	(e) 13	0	2	0	Concrete	.....	By six 1-in. bolts.
9	0	4	10	2	5	Solid rock (f)	Pine timbers, 29 × 29 in.	By three 1¼-in. bolts.
10	0	4	6	1	4	.....	.....	.....
9	4	4	7	2	4	Solid rock	Three timbers	.....
14	0	(e) 13	0	2	6	Solid rock	.....	.....
10	0	5	0	2	0	Solid rock	24 × 30-in. timbers	.....
9	0	(e) 10	0	2	6	Solid rock	18 × 12-in. timbers	.....
12	0	4	8	2	2	Solid rock	Planks	.....

<sup>1</sup> R. H. RICHARDT, "Ore Dressing," Vol. I.

(a) With width parallel to cam shaft. (b) 2 ft. thick. (c) For four batteries. (d) Planed and joined. (e) Length over all. The author is in doubt whether these are individual or combined mortar blocks. (f) Levelled by sand.

**Economies in Mill Parts in South African Gold Mills<sup>1</sup>**

**Stems.**—Stems are made at many mines from old camshafts or by faggoting up three old stems, at a cost averaging about £3. Stems are also repaired by welding on any suitable scrap material.

**Cams.** **New Modderfontein.**—Worn cams are brought up to shape by welding on pieces of rail or drill steel, at a cost of about £2 10s. per cam. The Knight Central fullers up the cams and, when necessary, welds in a piece of drill steel. The cost is stated to be £1 per cam. Ferreira Deep, Ltd., draws out old worn cams from root to standard size. This was the practice prior to the war. Crown Mines, Ltd., have made up a few cams by quasi-arc; first results not good; could be improved.

**Heads.** **Ferreira Deep, Ltd.**—When badly worn in socket, are heated up, compressed, re-bored, and put again into use.

**Shoes.**—Several methods are being tried for replacing broken shanks on shoes. New Modderfontein welds a worn-out shoe on to the broken one. This is economical if the weld holds, but definite information on this point is not yet available. A more usual method is to draw a new shank out of the shoe under hammer, which makes a satisfactory job, not, however, invariably successful, variation in quality of steel sometimes causing the shoe to split. It is stated that two hours are required to form a new shank like this, so the cost would be about 10s. Rose Deep bores out shoe and shrinks in a mild-steel shank at a cost of about £1. Another mine converts old tappets into shoes by welding on a shank.

**Dies.**—It is now the general practice to make dies by cutting an old head in two and filling holes with shoe shanks. This costs about 15s. for two dies.

**Camshafts.**—Witwatersrand Deep, Ltd., makes camshafts of five stems faggoted up together. Other mines weld up broken camshafts, with varying success.

**Blanton Gibs.**—Crown Mines, Ltd., has found a gib with feather on key much superior to the gib with two pins. The holes for pins are frequently drilled too deep and become a source of weakness in camshafts. The keyway would appear to add 50 per cent. to life of camshafts. At Ferreira Deep, Ltd., all pin holes in camshafts are drilled in fitting shop to gage  $\frac{1}{4}$ -in. deep, by using flat-faced drill with sleeve on to prevent possibility of drilling too deep. Considers cutting keyways and fitting key an unwarranted expense.

**Mortar-box Liners.**—At the Crown Mines, Ltd., mortar-box liners are made from old camshafts, at a cost 50 per cent. under imported ones. Similar liners are being made at some of the mines from old dies.

**Wood Guides.**—In connection with the practice of reboring wood stem guides, the Knight Central, Ltd., finds it pays to buy extra thick timber for the outside guides. In this mill

<sup>1</sup> Excerpt from an article in *Journ. Chem. Met. and Min. Soc. of S. A.*, December, 1918, p. 89.

the inside guide against the girt cannot be more than 4 in. thick, but the outer one can be  $4\frac{1}{2}$  in. This extra  $\frac{1}{2}$  in. gives a much longer life to half the guides. At the Ferreira Deep, Ltd., it is the practice to start guide with  $\frac{3}{4}$ -in. liner between halves, and as holes wear the liner is reduced until they come face to face;  $\frac{3}{4}$  in. is then cut away from the face of each half of guide block and restarted with a  $\frac{3}{4}$ -in. liner. The same procedure is carried out until blocks are completely worn out. Any odd hole worn out of proportion is lined with rawhide liner. By this method an average life of seven years is attained. Other mines adopt similar methods for economics in guide blocks. At the Crown Mines, Ltd., economy is achieved by lining guides with discarded leather ("Hendry") belting. Leather lining is not a new idea, but tacking on strips is novel having the advantage of enabling the shape of the box to be maintained. Still further improvement is effected by battery screening.

**Boilers.**—An interesting boiler repair job, which saved the company an expenditure of £300 on the boiler tubes, was carried out at the New Heriot Gold Mining Co., Ltd., Through removal for clearing, the tubes of an F. & C. boiler, 104 in number, had worn out at the ends. By cutting 2 in. off each end of these tubes and 4 in. off the boiler shell, all the tubes could be used again. The entire job cost £60. East Rand Proprietary Mines, Ltd., reported that the method was new to that mine. It is the practice to cut and weld tubes to suit the boiler, and the management considers this the better method. At the Crown Mines, Ltd., shortening of boilers has been in practice with Sterling boilers in order to make further use of tubes; it is also being done to facilitate transport.

**Crushers.**—The Bantjes Consolidated Mines, Ltd., carried out an economical repair job on a 30 by 12-in. Hadfield crusher. The engineer made a pair of case-hardened toggles from camshaft at a cost for labor of £3 5s., which allows an ample margin for power costs and similar charges, compared with the imported price of £9 10s. From similar material a wedge block toggle seat for 30 by 12 in. Hadfield crusher has been made. The Ferreira Deep, Ltd., uses F. & C. of Hadfield's 10 by 20 in. and 12- by 30-in. crushers. All toggles when worn badly are re-formed at a cost of 8 s. each. Broken toggle blocks are re-plated by mild-steel ones made at mine; also back wedges for fixed jaw faces. The East Rand Proprietary Mines, Ltd., have made wedge blocks and toggle seats from this material. Making crusher parts from old camshafts or suitable scrap has proved to be a valuable economy.

### Steam Stamps

The steam stamp is one in which a vertical stamp shaft is forced down to strike its blow, and lifted up preparatory to the next by means of a steam piston. The large ones are used solely in the Michigan Copper Country. A small steam stamp,

the Tremain, built by the Gates Iron Works, has been devised for treating gold ore, the idea being that they would be light to pack for the capacity obtained, and could be quickly mounted and dismounted.

STANDARD MINING SCREENS<sup>1</sup>

Mesh	Wire No.	Diam of wire, inches	Diam. of aperture, inches	Equivalent in millimeters	Per cent. of opening
1"	3	0.2437	0.7563	19.81	.....
3/4"	4	0.2253	0.5247	13.33	.....
5/8"	5	0.2070	0.4180	10.62	.....
2 mesh	8	0.1620	0.3380	8.59	.....
2 1/2	9	0.1483	0.2517	6.39	.....
3	10	0.1350	0.1983	5.04	.....
3 1/2	11	0.1205	0.1652	4.20	.....
4	12	0.1055	0.1445	3.67	.....
4 1/2	13	0.0915	0.1307	3.32	.....
5	13	0.0915	0.1085	2.76	.....
6	14	0.0800	0.0867	2.20	.....
7	15	0.0720	0.0709	1.80	.....
8	16	0.0625	0.0625	1.59	.....
9	17	0.0540	0.0571	1.45	.....
10	18	0.0475	0.0525	1.33	.....
12	19	0.0410	0.0423	1.07	25 80
14	20	0.0348	0.0366	0.93	26 01
16	22	0.0286	0.0339	0.86	30 47
18	23	0.0258	0.0298	0.76	30 24
20	24	0.0230	0.0270	0.69	29 16
22	25	0.0204	0.0251	0.64	31 35
24	26	0.0181	0.0256	0.60	32 27
30	28	0.0162	0.0171	0.43	27 03
40	31	0.0132	0.0118	0.30	21.15
50	34	0.0104	0.0096	0.24	25 00
60	36	0.0090	0.0077	0.20	18.45
64	37	0.0085	0.0071	0.18	.....
70	38	0.0080	0.0063	0.16	16.42
80	40	0.0070	0.0055	0.14	19 36

<sup>1</sup> R. H. RICHARDS, "Ore Dressing."

RITTINGER'S SIZES: Fine table ore, finer than 0.25 mm.; coarse table ore, 0.25-1 mm.; fine jigging ore, 1-4 mm.; coarse jigging ore, 4-16 mm.; lump ore, 16-64 mm.

#### Standard Screen Sizes as Recommended by the Bureau of Standards

Under the new standard a departure from any reference to mesh is made in either specifications or tolerances, the sieves being designated by arbitrary numbers. This screen scale

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is essentially metric. The sieve having an opening of 1 mm. is the basic one, and the sieves above and below this in the series are related to it by using the fourth root of 2, or 1.1892 as the ratio of the width of one opening to the next smaller opening.

## U. S. STANDARD SIEVE SERIES

Sieve no.	Sieve opening		Tolerance in average openings (limits)	Wire cloth suggested for commercial uses		
	In.	Mm.		Mesh	Wire, in.	Opening, in.
2½	.315	8 00	3119-.3181	2½	.080	.320*
3	.265	6 72	.2624-.2678	2½	.135	.265*
3½	.223	5 66	.2208-.2252	3	.072	.261
4	.187	4.75	1852-1888	3	.120	.213
5	.157	3.99	1555-1585	3½	.063	.223*
6	.132	3 36	.1307-.1333	3	.148	.185
7	.111	2.83	.1099-.1121	4	.063	.187*
8	.094	2 38	.0922-.0958	4	.092	.158
10	.079	2.00	.0775-.0805	4½	.063	.159
12	.066	1 68	.0647-.0673	5	.041	.159
14	.0557	1.41	.0546-.0568	4½	.092	.130
16	.0468	1 19	.0459-.0477	5	.063	.137
18	.0394	1 00	.0387-.0401	6	.035	.132*
0	.0331	0.84	.0322-.0340	6	.054	.113
5	.0278	0 71	.027-.0268	7	.032	.111*
30	.0234	0.59	.0227-.0241	7	.047	.096
35	.0197	0.50	.0191-.0202	8	.032	.093
40	.0166	0.42	.0161-.0170	7	.063	.080
				8	.047	.078
				9	.032	.079*
				10	.020	.080
				10	.035	.065
				12	.018	.065
				12	.017	.066*
				12	.028	.055
				14	.016	.055
				14	.025	.046
				16	.016	.0465
				12	.035	.048
				14	.032	.039
				16	.023	.0395
				18	.016	.0396
				18	.023	.0326
				20	.016	.034
				22	.018	.0275
				24	.014	.0277
				24	.0135	.0282
				24	.013	.0287
				24	.018	.0237
				26	.015	.0235
				28	.013	.0227
				30	.010	.0233
				28	.016	.0197*
				30	.014	.0193
				30	.0135	.0198
				30	.013	.0203
				32	.015	.0163
				35	.011	.0176
				32	.014	.0173

U. S. STANDARD SIEVE SERIES. *Continued*

Sieve no.	Sieve opening		Tolerance in average openings (limits)	Wire cloth suggested for commercial uses		
	In.	Mm.		Mesh	Wire, in.	Opening, in.
45	.0139	0 35	0134- 0143	40	.011	.014
				45	.009	.0132
				45	.0085	.0137
50	.0117	0.30	0112- 0121	40	.013	.012
				45	.011	.0112
				45	.010	.0122
				50	.0085	.0115
60	.0098	0.25	0094- 0101	55	.0085	.0097
				60	.007	.0097
				60	.0066	.0101
70	.0083	0 21	.0079- 0086	60	.0085	.0082
				60	.008	.0087
				64	.007	.0086
				70	.0062	.0081
80	.0070	.177			.0047	.0070*
100	.0059	.149			.0040	.0059*
120	.0049	.125			.0034	.0049*
140	.0041	.105			.0029	.0041*
170	.0035	.088			.0025	.0035*
200	.0029	.074			.0021	.0029*
230	.0025	.062			.0018	.0025*
270	.0021	.053			.0016	.0021*
325	.0017	.044			.0014	.0017*

\* Both standard and commercial.

STANDARD SAND AND CEMENT SIEVES<sup>1</sup>

Sieve no.	Sieve opening, in.	Wire diameter, in.	Tolerance in wire diameter
20	0.0335	0 0165	±0.0005
30	0 0223	0 0110	±0 0005
100	0 0055	0.0045	±0.0003
200	0.0029	0.0021	±0.0002

<sup>1</sup> Taken from *Bur. Standards Circ. 39.*

## COMMERCIAL BOLTING CLOTH

Silk bolting cloth			Equivalent grits XXX	Gauze stand- ard grits
Number of cloth	Mesh			
	XX cloth	XXX cloth	Number of XXX gauze	Number of standard
0000	18		16	18
000	23	..	22	24
00	29		28	30
0	38		40	44
1	48	...	46	50
2	54	...	50	54
3	58	...	54	58
4	62	.	58	62
5	66	...	64	68
6	74	...	72	
7	82	74		
8	86	82		
9	97	86		
10	109	97		
11	116	109		
12	125	116		
13	129	125		
14	139	129		
15	150	139		
16	157	150		
17	163	157		
18	166	163		
19	173			
20	178			
21	182			
25	200			

Cloth and gauze both 40 in. wide. Cloth comes in four weights: Standard, X, XX, and XXX. Mesh is exact count per linear inch.



## TYLER STANDARD SCREEN SCALE

Ratio $\sqrt{2}$ or 1.414		Mesh	Diam. wire, dec. of an inch
Opening in inches	Opening in millimeters		
1.050	26.67	.....	0.149
0.742	18.85	.....	0.135
0.525	13.33	.....	0.105
0.371	9.423	.....	0.092
0.263	6.680	3	0.070
0.185	4.699	4	0.065
0.131	3.327	6	0.036
0.093	2.362	8	0.032
0.065	1.651	10	0.035
0.046	1.168	14	0.025
0.0328	0.833	20	0.0172
0.0232	0.589	28	0.0125
0.0164	0.417	35	0.0122
0.0116	0.295	48	0.0092
0.0082	0.208	65	0.0072
0.0058	0.147	100	0.0042
0.0041	0.104	150	0.0026
0.0029	0.074	200	0.0021

I. M. M. STANDARD LABORATORY SCREENS<sup>1</sup>

Mesh, linear inch	Diameter of wire		Aperture		Screening area, per cent.
	In.	Mm. •	In.	Mm.	
5	0.1	2.540	0.1	2.540	25.00
8	0.063	1.600	0.062	1.574	24.60
10	0.05	1.270	0.05	1.270	25.00
12	0.0417	1.059	0.0416	1.056	24.92
16	0.0313	0.795	0.0312	0.792	24.92
20	0.025	0.635	0.025	0.635	25.00
30	0.0167	0.424	0.0166	0.421	24.80
40	0.0125	0.317	0.0125	0.317	25.00
50	0.010	0.254	0.01	0.254	25.00
60	0.0083	0.211	0.0083	0.211	24.80
70	0.0071	0.180	0.0071	0.180	24.70
80	0.0063	0.160	0.0062	0.157	24.60
90	0.0055	0.139	0.0055	0.139	24.50
100	0.005	0.127	0.005	0.127	25.00
120	0.0041	0.104	0.0042	0.107	25.40
150	0.0033	0.084	0.0033	0.084	24.50
200	0.0025	0.063	0.0025	0.063	25.00

<sup>1</sup> E. A. SMITH, "Sampling and Assay of the Precious Metals."

## SIZES OF ROUND AND SLOT-PUNCHED PLATE SCREENS

Needle number of screen	Approximate mesh of wire cloth to which openings correspond	Width of slot or diameter of hole in inches	Width of slot or diameter of hole in millimeters
1	12	0.058	1.47
2	14	0.049	1.25
3	16	0.042	1.07
4	18	0.035	0.89
5	20	0.029	0.74
6	25	0.027	0.69
7	30	0.024	0.61
8	35	0.022	0.56
9	40	0.020	0.51
10	50	0.018	0.46
11	55	0.0165	0.42
12	60	0.015	0.38
13	70	0.013	0.33

The needle-number is the number of the standard sewing needle that will just pass the screen.

Table taken from MACFARREN'S "Stamp Milling and Amalgamation."

## CONCENTRATION

The processes by which concentration may be carried on are: hand picking, wet-gravity separations (jigging, vanning, etc.), amalgamation, magnetic, electrostatic, pneumatic, adhesion or flotation, crushing and screening, decrepitation and screening, by varying electric conductivity. A short list of the chief concentrating machinery follows: •

**Ball-Norton Magnetic Separator.**—This consists of two revolving drums. Within each of these drums is a series of stationary electromagnets extending the working length of the drum, but corresponding only to a portion of the periphery. The ore is fed on the top of the first drum, and as the drum revolves, the magnetic particles adhere to it, while the non-magnetic fall into a tailings bin below. The magnetic particles, as soon as the portion of the drum on which they are passes beyond the magnets, are thrown off by centrifugal force against the second drum. This either rotates faster or has a weaker magnetic field than the first drum, so that those particles least strongly attracted by the first drum fall from the second, making a middlings product.

**Bartlett Table.**—This is a three-deck WILFLEY, the second deck re-treating the material from the first and the third deck re-treating the material from the second. An increasing amount of wash water is used on the successive decks.

**Bilharz, Corning, Luhrig and Stein Tables.**—These are side-bump tables having a table surface made of an endless traveling belt which has a plane surface.

**Bumping and Jerking Tables.**—These machines use mechanical agitation to bring the light and the heavy grains into their respective layers on a washing surface, and they use a bumping or jerking action to convey the heavy grains to one side or the other of the machine, while the current of surface water conveys the light grains to another side or end. They may be either side-bump, having the bump or jerk at right angles to the flow of the water, or end-bump, having the bump or jerk in the opposite direction from the flow of the water. See RITTINGER, BILHARZ, WILFLEY, BARLETT and OVERSTROM for side-bump tables. For further information see these types and "end-bump" tables.

**Canvas Tables.**—These are inclined rectangular tables covered with canvas. The pulp, to which clear water is added if necessary, is evenly distributed across the upper margin. As it flows down, the concentrates settle in the corrugations of the canvas. After the meshes are filled, the pulp feed is stopped, the remaining quartz is washed off with clear water, and finally the concentrates removed (by hose or brooms).

**Card Concentrator.**—A table made of two planes having a flexible joint between them dividing the table into two nearly equal triangles, forming a diagonal line along which concentrates and tailings part company.

**Conkling Magnetic Separator.**—The ore is fed on a conveying belt which passes under magnets, below which belts run at right angles to the line of travel of the main belt. The magnetic particles are lifted up against these cross belts and are thus removed.

**Deister Table.**—This is a riffled table in which the angle between the line of termination of the riffles and the direction of motion is not so acute as in the WILFLEY. It is also wider and shorter. The top is rhomboidal.

**Ding's Magnetic Separator.**—Material is fed up a vibrating conveyor and passes through successive zones of separation. These zones are covered by the rims of rotating wheels which carry secondary magnets. These carry the magnetic particles out of the field, are demagnetized, and drop the concentrates.

**Dodd Buddle.**—A round table resembling in operation a WILFLEY table, and also like the PINDER table (*q.v.*) except that it is convex instead of concave. The table does not revolve but has a peripheral jerking motion imparted to it circumferentially by means of a toggle movement.

**End-bump Tables.**—The heavy and light materials are separated by agitation and are propelled up the slope of the table by bumping action, but the wash water carries down the surface quartz at a higher speed than the bump can send it up. The Gilpin County, IMLAY and Golden Gate concentrators are the chief types.

**Ferraris Table.**—This table has a plane rubber belt traveling between rollers furnished with broad flanges to keep the belt in line. It has a slope from side to side. The feed is at an upper corner, and washing is by jets directed across the table.

**Film-sizing Tables.**—These use the relative transporting power of a film of water flowing on a quiet surface, which may be either rough or smooth, to act upon the particles of a water-sorted product. The smaller grains, of high specific gravity, are moved down the slope slowly or not at all by the slow under-current; the larger grains, of lower specific gravity, are moved rapidly down the slope by the quick upper current. These tables may be classified as: Surface tables, from which the products are removed before they have formed a bed, so that the washing is always done on the same surface; and building tables or buddles, on which the products are removed after they have formed a bed.

**Frue Vanner.**—This consists essentially of a rubber belt traveling up a slight inclination. The material to be treated is washed by a constant flow of water while the entire belt is meanwhile shaken from side to side. Other vanners of the side-shake type are the TULLOCH, JOHNSON and NORBOM.

**Gates Canvas Table.**—A large form of inclined canvas table in which the pulp is first classified, then distributed along the upper edge of the table. The concentrates are caught in the warp of the canvas and after this is full, treatment must be stopped while the concentrates are swept or sluiced off.

**Gröndal.**—A magnetic separator consisting of a vertical revolving cylinder made up of rings of cast iron with the spaces between containing the wires for the electric current. Each ring is so magnetized as to be a little stronger than the one above. There is another cylinder of wood studded with soft wrought-iron pegs, a ring of pegs being opposite each cast-iron ring. The magnetic portion of the ore (usually crushed below 12 mesh) is carried around on the cast-iron rings until it gets near the pegs, to which it jumps because of their induced magnetism. It is then carried on these pegs out of the magnetic field and thrown off.

**Hallett Table.**—This is like the WILFLEY except that the tops of the riffles are in the same plane as the cleaning planes and the riffles are sloped toward the wash-water side.

• **Hancock Jig.**—A jig with movable sieve having both an up-and-down and a reciprocating motion.

**Harz or Plain Eccentric Jig.**—One in which pulsion is given intermittently with suction. The periods devoted to them are about equal.

**Huff Separator.**—An electrostatic machine depending on the repelling and attracting action of electrically charged particles. The feed is passed over a roller, and the constituents take various electrical charges according to conductivity and are repelled accordingly. This machine is superseding the old BLAKE type.

**Isbell Table.**—A table with a reciprocating motion in which there is no cross wash water. The bed of pulp is deep as in a jig, and heavy material goes to the bottom. The concentrates and tailings are then split by means of a cut-out which can be adjusted vertically to skim at any height desired. The riffles make an angle of about 20° with the line of motion of the table.

**James Concentrator.**—The table deck is divided\* into two sections, flexibly joined together on a line oblique to the line of motion of the table. One section is riffled for the coarse material while the other section is smooth, to allow the settling of the fine particles which will not settle on a riffled surface. By means of the joint, the slope of the sections can be varied independently.

**Johnston Vanner.**—The chief difference between this and a **FRUE** (*q.v.*) is that the belt is given an undulating motion, designed to prevent sands from piling up against the edges of the belt.

**Kieves.**—These are strong tubs with sides flaring upward, in which separation is effected by mechanical agitation in a deep mass of thick pulp. Stirring paddles are used for preliminary mixing, and hammers or heavy striking bars for the final separation. They are used to finish the concentration of fine products that are nearly rich enough to ship.

**Log Washer.**—This is a slightly slanting trough in which revolves a thick shaft or log, carrying blades obliquely set to the axis. Ore is fed in at the lower end, water at the upper. The blades slowly convey the lumps of ore uphill against the current, while any adhering clay is gradually disintegrated and floated out the lower end.

**Overstrom Table.**—A **WILFLEY** squeezed out into a diamond shape (rhomboid), thus eliminating the waste corners.

**Pinder Concentrator.**—A revolving table on which are tapering spiral copper cleats on a linoleum cover. The tailings are washed over the riffles and off the edge while the concentrates are delivered at the end of the riffles.

**Richard's Pulsator Jig.**—An outcome of the pulsator classifier, in which a pulsating column of water is used in the jig.

**Rittinger Table.**—A side-bump table with plane surface, using a cam, spring and bumping post.

**Spitzlutte.**—This is a classifying device consisting of a V-shaped box, as distinguished from the pyramidal boxes of the spitzkasten. Classification is dependent on the force of a stream of water admitted at the bottom.

**Sutton, Steele and Steele Dry Table.**—A concentrator of the **WILFLEY** type in motion, but instead of using water, stratification is by means of rising currents of air. The heavy grains are pushed forward by the head motion, while the lighter grains roll or flow down the slope toward the tailing side.

**Triumph Concentrator.**—This machine resembles a **FRUE** vanner (*q.v.*), but the shaking motion is endwise instead of side to side.

**Trough Washer.**—This is used to float adhering clay or fine stuff from the coarser portions of an ore. In its simplest form it is a sloping wooden trough,  $1\frac{1}{2}$  to 2 ft. wide, 8 to 12 ft. long and 1 ft. deep, open at the tail end, but closed at the head end.

**Ullrich Magnetic Separator.**—These machines have powerful electromagnets of wedge section. The material is treated on rolls on which magnetism is induced. They consist of alternate

disks of soft iron and some non-magnetic material. The ore is fed over the first roll, which removes the most magnetic material, and the tailings go on to the second which is weaker, where a second separation is made.

**Vanner.**—See **FRUE vanner** for general description of the side-shake type. There is also an end-shake type, which includes the **Triumph concentrator**, **EMBRY concentrator**, and **WOODBURY vanner**, and a gyrating type, the **ELLIS**. A 4-ft. vanner may take up to 13 gal. of water per minute and the weight of water to dry sand may rise to 10.7:1. The pulp bed may be as much as 0.45 in. thick.

**Wetherill's Magnetic Separator.**—Parallel form. Two flat belts, the upper of which is the wider, run parallel to each other. The magnets are long and set obliquely to the belts. Consequently magnetic particles are drawn up against the upper belt, move diagonally out and as they pass beyond the influence of the magnets, fall from the edge past the other belt into a concentrates bin. Another form operates by belts moving across the line of travel of the main belt.

**Wilfley Slimer.**—A form of shaking canvas table which is given a vanner motion.

**Wilfley Table.**—A side jerk table with a riffled surface. The light and heavy grains are separated into layers by agitation, and the jerking action then throws the heavy grains toward the head end, while the light grains are washed down over the cleats into the tailings box. The table tapers toward the head end, and the riffles are progressively longer toward the tailings side. The **DODD**, **CAMMETT**, **HALLETT** and **WOODBURY** are very like it.

**Woodbury Jig.**—A jig with a plunger compartment at the head end, so that the material is given a classification in the jig.

**Woodbury Table.**—A table of the general **WILFLEY-OVERSTROM-CARD** type, with the riffles parallel to the tailing side, and a hinged portion without riffles (unlike the Card). The table top is a rhomboid, and the riffles gradually shorten as they near the tailings side.

## CONCENTRATING AND CYANIDING MACHINERY

The following list includes the most important types of concentrating and cyaniding machinery not already described under crushing and concentrating equipment.

**Akins Classifier.**—A classifier of the free-settling type, in which the heavy material is driven up an inclined plane by means of an interrupted-flight screw conveyor.

**Blaisdell Reclaiming Apparatus.**—Apparatus for automatically discharging sand tank having a central bottom opening. Consists of a central vertical shaft carrying four arms fitted with round plow disks. Sand is plowed toward central opening and discharged on a conveyor belt.

**Blaisdell Loading Machinery.**—Apparatus for loading sand tanks. Consists of a rapidly revolving disk with curved radial

vanes. Disk is hung on a shaft in tank center. Sand dropped on disk is distributed over the entire tank area.

**Brown Tank.**—As ordinarily used it is a cylindrical tank 45 ft. high and 15 ft. in diameter, ending at the lower end in a 60° cone. Within the tank is a hollow column about 15 in. in diameter extending from about 18 in. of the bottom to within about 8 in. of the top. A 1½-in. air pipe discharges air upward at and into the tube. The apparatus works on the air-lift principle, the pulp in the tube being lightened by the air, flowing upward, and being discharged at the top, more pulp flowing in at the bottom to take its place.

**Bunker Hill Screen.**—A rotating screen shaped like a funnel. Material is delivered inside the funnel, undersize passing through the screen while the oversize is discharged through the funnel neck.

**Burt Filter.**—This is a stationary, intermittent filter in which the leaves are suspended vertically in a round tank set on a considerable incline. The leaves are therefore ellipses. The slime cake is discharged by introducing air and water into the interior of the leaf. There is also a newer Burt filter of the continuous rotating-drum type.

**Butters Filter.**—This is a stationary, intermittent vacuum filter. The leaves are arranged in a box having a pyramidal bottom. When the pulp is introduced a vacuum is applied until a cake from 1 to 2 in. in thickness is formed. The surplus solution is then removed from the box and wash solution or water introduced. After removing the wash solution, either the box is filled with water or the cake dropped and sluiced out.

**Callow Screen.**—A classifying screen using the traveling-belt principle, the screen cloth forming the belt member. It passes over two drums, or pulleys, oversize being discharged while the belt travels under the drums.

**Callow Cone.**—This is a conical settling tank with vertical central feed, peripheral overflow, annular launder to collect and convey away the overflow, and a spigot in the form of a gooseneck to discharge the tailings.

#### CALLOW CONE TEST ON BUTTE COPPER SLIMES

	Total gal. per min.	Grams per gal.	Tons per 24 hr.	Assay per cent. Cu	Oz. Ag per ton
Feed.....	1792.7	41.15	117.16	2.80	2.81
Overflow.....	1495.0	16.25	38.45	1.815	2.36
Spigot product..	297.5	154.5	73.13	3.5	3.34

**Dehne Filter Press.**—One of the best known of the standard plate-and-frame presses, which see.

**Dorr Agitator.**—An agitating machine based on the thickener principle. It is essentially a DORR thickener equipped with a central air-lift.

**Dorr Classifier.**—A machine to diminish the amount of water required for classification by raking the heavier grains up an inclined plane against a light current of water, which washes away the lighter material. It is of the intermittent type.

**Esperanza Classifier.**—A classifier of the free-settling type in which the settled material is removed by dragging it up an inclined plane by means of a continuous belt of flat blades or paddles. This is continuous in its operation.

**France Screen.**—A traveling belt screen in which the screen-cloth is mounted on a series of separate pallets, thus avoiding bending the screen as it goes over the pulleys.

**Hunt Continuous Filter.**—A horizontally revolving continuous vacuum filter. It consists of an annular filter bed, usually of triangular wooden slats filled with coarse sands. The vacuum withdraws part of the pulp moisture as soon as the bed is formed. A spray then washes it after which the vacuum dries it and the material is then scraped off.

**Hydrotator Classifier.**—This consists of a circular tank in which there is a free-settling zone at the top; beneath that is a turbulent zone, a portion of the water being drawn off and returned from the top of this zone through an inverted lawn sprinkler near the bottom of the tank. The effluent from the "lawn-sprinkler" stirs the sand on the bottom and assists in desliming it. The hydraulic water is also introduced by the "lawn sprinkler." The upward velocity in the turbulent section is the volume of the hydraulic water plus the feed water plus the water drawn off at the top of the turbulent zone less the sand-discharge water divided by the effective area. The upward velocity in the free-settling zone is the volume of hydraulic water plus feed water less the sand-discharge water divided by the effective area.

**Impact Screen.**—A type in which the screen moves with the load of material, bringing up against a stop so as to throw the material forward on it. The Imperial is probably the best known type.

**Imperial Screen.**—A pulsating screen in which the ore is thrown up in the air as well as moved forward over the screen.

**Kelly Filter.**—This is an intermittent, movable pressure filter. The leaves are vertical and are set parallel to the axis of the tank. Pulp is introduced into the tank (a boiler-like affair) under pressure and the cake formed. The head then is unlocked and the leaves run out of the tank chamber, by means of a small track, and the cake is dropped. The carriage and leaves are then run back into the tank and the cycle begun again.

**King Screen.**—A drum-type screen in which the pulp to be screened is delivered on the outside, the undersize passing through the screen and discharging through the open end.

**Maxton Screen.**—A screening machine of the trommel class, open at each end and rotating on rollers supporting the tube through tires at each end. There are radial elevating ribs, to prevent wear of screen cloth and to elevate the oversize.



Unscreened material is delivered on the inside screen surface, undersize passing through and oversize being elevated and discharged into a separate launder.

**Merrill Filter Press.**—A variation of the plate-and-frame press.

**Moore Filter Press.**—The best known of the movable, intermittent vacuum filters. A series, "or basket," of leaves is fastened together in such a way that it may be dropped in a pulp tank and kept submerged until a cake is formed. It is then transferred by crane to an adjoining wash-solution tank and washed. The basket is then lifted out of this and the cake dropped.

**Newaygo.**—A slanting screen down which the material to be screened passes. The screen is kept in vibration by the impact of a vast number of small hammers.

**Oliver Continuous Filter.**—This consists of a revolving drum prepared as a leaf-filtering surface and divided into compartments, each of which is connected to a vacuum pipe and to a pipe for admitting compressed air. The drum is partly immersed in a tank or box of thick pulp and revolves at a slow rate of speed. The vacuum causes a  $\frac{1}{4}$  to  $\frac{1}{2}$ -in. slime cake to form; after emerging, the solution is sucked out of the adhering cake; a wash is then given and displaced by air as far as possible; and finally the cake is dropped by compressed air.

**Ovoca Classifier.**—A classifier of the free-settling type in which the heavy material is removed by a double-screw, continuous-flight conveyor, working up an inclined plane.

**Pachuca Tank.**—Same as the BROWN tank.

**Paddle-wheel Agitator.**—The simplest form, in which the solids are kept in suspension by paddles. It is difficult to do with sand, the machine being difficult (if not impossible) to start if sand packs around the blades, and it is expensive both in operating and in repair costs.

**Parral Agitator.**—An agitator using a number of small air lifts disposed about a circular, flat-bottomed tank in such a way as to impart a circular swirling motion to the pulp.

**Patterson Agitator.**—An agitator of the PACHUCA-tank type in which the air is replaced by solution or water, under pressure from a centrifugal pump.

**Plate-and-frame Filter Press.**—The old style press. It consists of plates with a girdiron surface alternating with hollow frames, all of which are held by means of lugs, on the press framework. The corners of both frames and plates are cored to make continuous passages for pulp and solution. The filter cloth is placed over the plates. The pulp passageway connects with the large square opening in the frame; the solution passageways with the girdiron surface of the plate. The DEHNE and the MERRILL are well-known types.

**Portland Filter.**—A rotary suction filter similar in general arrangement to the Oliver.

**Richard's Pulsator Classifier.**—A classifier operating by a pulsating current of water without a screen. The pulp grains

fall through a sorting column against an upward pulsating current of water.

**Ridgeway Filter.**—This is a horizontal revolving, continuous vacuum filter. The surface is an annular ring consisting of separate trays with vacuum and compressed air attachments. The filtering surface is on the under side, the trays being dipped into the tank of pulp to form the cake, and then lifted out of it.

**Richard's Shallow-pocket Hindered-settling Classifier.**—A series of pockets through which successively weaker streams of water are directed upward. The material that can settle does so and is drawn off through spigots.

**Sherman Settler.**—A series of cylindrical tanks with conical bottoms having central feed and a peripheral overflow. The tanks continually decrease in depth and increase in diameter.

**Superthickener.**—Essentially a cylindrical tank having a permanent porous false bottom supporting a destructible filter bottom several feet thick composed of fine granular particles. Thickening takes place both by overflow of a clear decantate and by the underflow of a filtrate. The filter bottom (sand or the like) is slowly cut away by a spiral sweep, thus continually giving a fresh unclogged filter bed. The superthickener is the invention of H. S. Coe.

**Trent Agitator.**—This agitator has the arms of the paddle-wheel type, but they are hollow, and pulp solution or air is discharged from nozzles on these arms, thus causing the stirrer to rotate.

**Trommel.**—A revolving screen set at an angle. The material to be screened is delivered inside the trommel at one end. The fine material drops through the holes; the coarse is delivered at the other end.

**Vibracone.**—A vibrating screen manufactured by the Stephens-Adamson company, in which the feed is from a saucer-shaped distributor onto a conical surface kept in vibration by a ratchet motion.

## THICKENER CALCULATIONS

\* Let it be supposed that a test sample has been prepared showing a proportion of water to solids of 14.04 to 1 and that after 17 hr. the pulp has settled to 1.13 parts of water to 1 of solids and only to 1.12 to 1 after 24 hr., then evidently the economic point of thickening is 1.13 to 1. Settlement tests show an average rate of 1.78 in. per hour, hence there can be decanted 1.78 cu. ft. times 62.3 or 111 lb. of water per hour per square foot of tank surface. Since the feed contains 14.04 water to 1 of solids and the discharge 1.13 water to 1 of solids the overflow must contain the difference between the two ratios or 12.91 parts of water in the overflow to 1 part solids settled and is 111 lb. per hour. The solids consequently represent 8.59 lb. solids settled per hour or 206 lb. of solids in 24 hr. For a ton there would then be required 9.7 sq. ft. for 24 hr. which is the capacity of the tank with the dilution given.

The computations may be expressed in the following formula  
 Square feet of tank surface required per ton dry per 24 hr. =  

$$\frac{(F - D)2000}{R \times 62.3 \times 24}$$

where  $R$  = Rate of settlement in feet per hour,  
 $F$  = Parts of water to 1 part solids in feed,  
 $D$  = Parts of water to 1 part solids in discharge.

The series of tests which follow the first one will give the following factors and capacities:

$R$	$F$	$F - D$	Square feet tank surface required per dry ton per 24 hr.
1.250	11.18	10.05	10.70
0.666	8.32	7.19	14.40
0.464	6.89	5.75	16.60
0.345	5.47	4.34	16.85
0.2331	4.03	2.90	16.65
0.150	2.607	1.477	13.10

The series of tests show that 16.85 sq. ft. of surface will be required for each ton settled.

With 8 parts of liquid to one of solids the settling area required by Dorr thickeners ranges from 5 to 25 sq. ft. per ton of solids.

**Working Data for Harz Jigs.**—The proper length of stroke and the proper number of strokes for various sized grains is shown by the curve Fig. 1. For extra close work and in lack of other data the capacity of a jig in tons per 24 hr. per square inch of screen surface may be taken as low as  $(d)^{1/2}/100$ , where  $d$  is the average diameter of grain fed in millimeters. For roughing work and on easy problems the capacity figure given by this formula may be greatly exceeded. It may run to as high as  $(d)^{1/2}/20$ . The average capacity is nearer to the last figure.

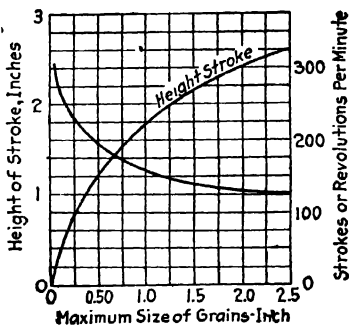


FIG. 1.

**Engineering Data on the Classifiers.**—Complete data on the performance of these machines is very difficult to obtain. The data given below is the most complete for the installations given that it has been possible to gather.

The question of the capacity of the Dorr and Akins machines for any mesh separation desired in terms of dry tons is a question which cannot be answered owing to the number of varying factors affecting tonnage. Among these factors are the proportion of moisture entering the classifiers, the screen analysis of the material entering, the readiness with which the finer portions will settle, etc. The tabulation given below is approximately correct for the varying factors which it illustrates. To convert the tonnage into cubic feet capacity multiply by 22. The power required does not exceed 0.01 to 0.02 hp. per ton of dry material treated daily.

### Utah Copper Company

#### 54-in. Standard Akins Classifier

##### Feed:

Tonnage to classifier per 24 hr., 1050 tons dry.

Per cent. of solids	37.50
Per cent. of moisture	62.50
Ratio of water to solids	1 $\frac{2}{3}$

##### Products of Classifier:

Sands raised 630 tons per 24 hr., dry.

Per cent. of solids	60.63
Per cent. of moisture	39.37
Ratio of water to solids	0.65

Slimes overflowing 420 tons per 24 hr., dry.

Per cent. of solids	25.16
Per cent. of moisture	74.84
Ratio of water to solids	2.98

Screens			Feed, per cent. weight of material	Sands, per cent. weight of material	Slimes, per cent. weight of material
Openings, in.	Mesh	Diameter wire, in.			
0.263	3	0.070	0.08	0.55	
0.185	4	0.065	0.06	0.17	
0.131	6	0.036	0.36	0.70	
0.093	8	0.032	0.52	1.16	
0.065	10	0.035	1.19	2.63	
0.046	14	0.025	2.22	4.62	0.07
0.0328	20	0.0172	5.36	9.92	0.33
0.0232	28	0.0125	11.13	20.72	1.25
0.0164	35	0.0122	16.35	21.40	7.04
0.0116	48	0.0092	9.91	10.17	9.16
0.0082	65	0.0072	10.02	7.81	9.70
0.0058	100	0.0042	6.07	3.60	7.94
0.0041	150	0.0026	4.74	2.52	7.63
0.0029	200	0.0021	3.79	1.28	5.23
.....	280	.....	.....	0.63	2.53
.....	through 280	.....	28.20	12.12	49.12

## United Eastern Mill

Special 3 ft. 0 in. Wide by 14 ft. 8 in. Long Dorr Simplex Classifier

*Feed:*

Tonnage to classifier per 24 hr. 610 tons, dry. (This classifier working in closed circuit with a ball mill.

Original rate of feeding 280 tons per 24 hr.)

Slope of classifier, 3 in. per foot

Speed, 34 strokes per minute.

Per cent. of moisture..... 39 2

Per cent. of solids..... 60.8

Ratio of water to solids..... 0.65:1

*Products of Classifier:*

Sands raised 330 tons per 24 hr., dry.

Per cent. of solids..... 80.0

Per cent. of moisture..... 0 0

Ratio of water to solids..... 0.25:1

Slimes overflowing 280 tons per 24 hr., dry.

Per cent. of solids..... 47 5

Per cent. of moisture..... 52.5

Ratio of water to solids..... 1.11:1

Screens			Feed, per cent. weight of material	Sands, per cent. weight of material	Slimes, per cent. weight of material
Openings, in.	Mesh	Diameter wire, in			
0.263	3	0.070			
0.185	4	0.065			
0.131	6	0.036			
0.093	8	0.032			
0.065	10	0.035	4.4	6.4	
0.046	14	0.025	12.2	18.3	
0.0328	20	0.0172	11.6	17.9	
0.0232	28	0.0125	9.6	5.8	
0.0164	35	0.0122	7.8	12.3	
0.0116	48	0.0092	5.2	10.8	1.2
0.0082	65	0.0072	5.0	6.2	3.0
0.0058	100	0.0042	4.8	4.5	6.4
0.0041	150	0.0026	3.8	2.1	6.6
0.0029	200	0.0021	0.4	0.6	5.2
.....	through	.....	35.2	5.1	77.6
	200				

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## Timber Butte Milling Co.

45-in. Submerged-type Akins Classifier with Overflow  
Raised 10 in.

### Feed:

Tonnage to classifier 350 tons per 24 hr., dry. (Feed consists of tailings from Wilfley roughing tables, zinc department of mill.)

Slope of classifier  $2\frac{1}{8}$  in. to 1 ft.; 8 r.p.m., power required to drive 1.39 hp.

Per cent. of solids..... 41.40

Per cent. of moisture..... 58.60

Ratio of water to solids..... 1.42

### Products of Classifier:

Sands raised 217 tons per 24 hr., dry.

Per cent. of solids..... 76.3

Per cent. of moisture..... 23.7

Ratio of water to solids... 0.31

Slimes overflowing 133 tons per 24 hr., dry.

Per cent. of solids... 23.7

Per cent. of moisture... 76.3

Ratio of water to solids... 3.2

Screens			Feed, per cent weight of material	Sands, per cent. weight of material	Slimes, per cent. weight of material
Openings, in.	Mesh	Diameter wire, in.			
0.263	3	0.070			
0.185	4	0.065			
0.131	6	0.036			
0.093	8	0.032			
0.065	10	0.035			
0.046	14	0.025	27.0	55.0	
0.0328	20	0.0172	11.0	13.0	1.9
0.0232	28	0.0125	9.0	9.0	9.6
0.0164	35	0.0122	7.0	5.0	10.3
0.0116	48	0.0072	7.0	4.0	9.8
0.0082	65	0.0072	6.5	2.0	8.4
0.0058	100	0.0042	5.0	2.0	7.2
0.0041	150	0.0026	5.0	1.5	6.8
0.0029	200	0.0021	2.5	1.5	7.5
.....	through 200	.....	20.0	7.0	38.5

CAPACITY OF DORR AND AKINS CLASSIFIERS PER FOOT OF WIDTH

Mesh of separation desired	Overflow capacity, tons dry per 24 hr.	Raising capacity, tons dry per 24 hr.	Dorr, strokes per min.	Akins, revolutions of spiral per minute	Dorr slope in. per ft.	Akins slope	Water to pulp in feed
28	65 to 85	130	25 to 30	15 to 20	3/4 to 3/4	28" ↓ 24"	2:1
48	60 to 70	125	25 to 30	15 to 20	3 to 3/4		3:1
65	40 to 50	100	20 to 25	12 to 15	2 3/4 to 3		3.5:1
100	30 to 40	90	16 to 20	10 to 12	2 1/2 to 2 3/4		4-6:1
150	20 to 30	75	12	8	2 to 2 1/4		6-10:1
200	10 to 20	60	12	6	2 to 2 1/4		10-15:1

POWER USED IN BOSTON & MONTANA CONCENTRATOR

Machine	R.p.m.	Horsepower required
Hancock jig.....	62	3.41
Evans jig.....	190	0.50
Trommel (3×6-ft.).....		0.30
Overstrom table.....	251	0.364
Wilfley table.....	251	0.352
Vanner (4-ft.)....	182	0.230

Power Used in Concentrating Mills

As an indication of what power may be needed in milling, the following table is taken from R. H. RICHARD'S "Ore Dressing," Vol. IV, page 1929. The figures are those for the Cananea Consolidated Copper Co.'s No. 2 and No. 1 mills:

	Horsepower
20 trommels 4 × 5 ft. and 4 × 8 ft.....	20
4 16-in. elevators, 46 ft. between pulley centers.....	10
4 sets 16 × 36-in. rolls at 80 r.p.m.....	20
6 one-compartment bull jigs (4 active).....	8
16 two-compartment middle jigs.....	16
16 three-compartment sand jigs.....	16
2 dewatering trommels.....	1
2 chip trommels.....	1
10 shovel wheels with shafting.....	3
2 centrifugal pumps, 1200 gal. per minute, 40-ft. lift.....	60
8 5-ft. Bryan mills.....	144
38 Wilfley tables with line shafting.....	25
36 6-ft. Frue vanners with line shafting.....	8
2 centrifugal pumps.....	25
6 shaking launders.....	3
2 middling elevators.....	5
2 pulp elevators.....	3
Friction of engine and remaining shafting.....	80
Total on mill engine.....	472
1400 tons of ore treated per day.	

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	Horsepower
24 trommels.....	12
2 No. 1 elevators.....	13
2 No. 2 elevators.....	14
2 No. 3 elevators.....	8
2 No. 4 elevators.....	8
8 bull-jigs (4 active).....	8
16 two-compartment jigs.....	16
8 three-compartment jigs.....	8
2 Bryan mills.....	36
2 No. 1 centrifugal pumps.....	40
2 shaking launders and 2 shovel wheels.....	2
2 16 × 36-in. Davis rolls.....	22
4 14 × 27-in. Davis rolls.....	40
shafting and belts.....	40
engine and jackshaft friction.....	50
Total engine load.....	317
42 Wilfley tables.....	26
36 six-foot Frue vanners.....	8
2 10 × 48-in. sand pumps.....	3
1 No. 2 centrifugal pump.....	15
Friction of transmission.....	13
Total motor-driven load.....	65
Total power required in mill.....	382
1400 tons of ore treated per day.....	

### Power Used in Mills

(Data furnished by General Engineering Co.)

- Crushers.** *Blake*.—7 × 10, 8 h.p.; 9 × 15, 15 h.p.; 10 × 20, 20 h.p.; 15 × 24, 30 h.p.  
*Dodge*.—4 × 6, 2 h.p.; 7 × 10, 7 h.p.; 11 × 15, 15 h.p.  
*Gates*.—D Style No. 1, 10 h.p.; No. 2, 15 h.p.; No. 3, 25 h.p.; No. 4, 30 h.p.; No. 5, 40 h.p.; No. 6, 60 h.p.; No. 7, 125 h.p.; No. 8, 150 h.p.  
**Mills.**—10-stamp, 90 8-in. drops per min., 750 lbs., 15 h.p.; 850-lb., 17 h.p.; 950-lb., 19 h.p.; 1000-lb., 20 h.p.  
*Tubes*.—5 × 14-ft., 30 h.p.; 5 × 22-ft., 70 h.p.; 4 × 20-ft., 50 h.p.  
*Chilian*.—4-ft., 6 h.p.; 5-ft., 12 h.p.; 6-ft., 25 h.p.  
*Huntington*.—3½-ft., 4-5 h.p.; 5 ft., 6-7 h.p.; 6-ft., 8-10 h.p.  
**Rolls.** *Cornish*.—12 × 20, 12 h.p.; 14 × 27, 16 h.p.; 16 × 36, 25 h.p.  
**Sample Grinders.**—No. 1, 3 h.p.; No. 2, 4 h.p.  
**Amalgamating Pans.**—5-ft., 4 h.p.; 8-ft., 6 h.p.  
**Grinding Pans.**—5-ft., 6 h.p.; 8-ft., 9 h.p.  
**Settlers.**—8-ft., 3 h.p. **Agitators.**—8-ft., 3 h.p.  
**Clean-up Pans.**—48-in., 1½ h.p.  
**Hendryx Agitator.**—5 h.p.  
**Revolving Screens.**—½ h.p. **Revolving Dryers.**—5 h.p.  
**Wilfley Tables.**—¾ h.p. **Frue Vanners.**—½ h.p.  
**Hancock Jigs.**—5 h.p. **Harz Jigs.**—(per compt.) 1 h.p.  
 (The data is to be considered approximate only.)



WATER USED IN MILLS<sup>1</sup>

Mill	Water used per 24 hr., gal.	Capacity of mill per 24 hr., tons	Water used per ton, gal (c)	Remarks, stamps
GOLD STAMP MILLS				
Hector Mining Co., Telluride, Colo. . .	51,840(a)	90	576.0	30
Franklin Mining, Placerville, Calif. . .	96,336(a)	60	1,605.6	10
North Star, Grass Valley, Calif. . .	156,193(a)	64	2,440.5	40
Empire Mill, Grass Valley, Calif. . .	240,750(a)	60	4,012.5	40
Idlewild Mill, Greenwood, Calif. . .	239,040(a)	115 to 128	1,867.5 to 2,078.6	40
Grand Victory, Placerville, Calif. . .	259,600(a)	100 to 150	1,730.6 to 2,596.0	30
Wildman, Sutter Creek, Calif. . .	151,000(a)	93	1,623.7	50
Madison, Angels Camp, Calif. . .	123,840(a)	200	619.2	40
West Waverley, Waverley, N. S. . .	216,000	50 to 65	3,324.6 to 4,320.0	20
Montana, Marysville, Mont. . .	213,120	105	2,029.7	60
Utica, Angels Camp, Calif. . .	185,760(a)	300	619.2	60
Stickles Mill, Angels Camp, Calif. . .	185,760(a)	300	619.2	60
Zeile Mining Co., Jackson, Calif. . .	179,676(a)	150	1,197.8	40

## COMBINATION SILVER MILLS

Montana, Marysville, Mont	252,576	110	2,296.1	50
Eureka Hill, Eureka, Utah	{ Steam power 15,360(b) Concentrating 39,480(b) }	120	457.0	60
Mammoth, Tintic, Utah	{ Fresh 70,000 Repumped 30,000 }	100	1,000.0	40
• • •	100,000			

## JIGGING MILLS

Friedensville Zinc, Friedensville, Penn. . .	62,000(c)	120 to 135	459.3 to 516.7	...
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MILLS WITH JIGS, VANNERS AND TABLES

Mill	Water used per 24 hr., gal.	Capacity of mill per 24 hr., tons	Water used per ton, gal. (c)	Remarks, stamps
Old Jordan & Galena, Bingham, Utah.....	237,600	175	1,357.6	.....
Central Lead, Flat River, Mo.....	1,152,000	175	6,582.8	.....
St Joseph Lead Co., Bonne Terre, Mo.....	2,250,000	900	2,500.0	.....
Bullion Beck & Champion, Eureka, Utah.....	129,600	200	648.0	.....
Smuggler, Aspen, Colo. ....	900,000 (a) (c)	100	9,000.0	.....

## MONTANA COPPER SULPHIDE MILLS

Butte & Boston, Butte, Mont .....	Flows in { Pumped { Repumped	1,000,000 1,440,000 700,000	{ { {	2,000 2,880 1,400	.....
Colo. Sm. & Ref., Butte, Mont.	3,140,000			6,280	.....
Parrot Silver & Copper, Butte, Mont..	1,064,000 • 1,200,000 to 1,400,000		275 to 300 300 to 350	3,546.7 to 3,869.0 4,000	.....

## LAKE SUPERIOR NATIVE COPPER MILLS WITH STEAM STAMPS

Calumet & Hecla, Calumet, Mont. ....	20,000,000	2,080	9,615.4	.....
Franklin, Hancock, Mich .....	3,744,000 (d)	450	8,320.0	.....
Osceola, Mich .....	12,000,000	1,260	9,523.8	.....
Quincy, Hancock, Mich .....	12,000,000	1,700 to 1,900	6,315.8 to 7,058.8	.....
Tamarack, Houghton, Mich.....	10,000,000	1,500	6,666.7	.....

(c) The mill is run by water power, and this figure does not include the water used for power. (d) This does not include what is repumped. (e) This is for 10 hours only. (f) This is the water that leaves the mill with the tailings. The amount of water coming to the mill is slightly larger.

<sup>1</sup> The table is from RICHARDSON'S "Ore Dressing," Vol. II, and consequently represents the practice of 15 years ago. For all that, it is a valuable guide to have as to what water may be necessary.

## WATER CONSUMPTION IN VARIOUS MILLS

	Gal. water per 24 hr.	Tons ore per 24 hr.	Water used per ton of ore		Remarks
			Gallons	Tons	
	GOLD STAMP MILLS <sup>3</sup>				
Haile, South Carolina.	360,000	150	2,400	10	60 stamps

## JIGGING MILLS

Smuggler Mining Co...	2,160,000	400	5,400	22.5	.....
St. Joe Lead .....	4,000,000	1,200	3,333	13.9	.....
St. Louis Sm. & Ref....	5,760,000	1,800	3,200	13.3	.....
Block 10.....	864,000 <sup>1</sup>	575	1,500 <sup>1</sup>	6.26	Australian
	69,000		120	0.5	
Daly-West.....	504,000 <sup>1</sup>	500	1,008 <sup>1</sup>	4.2	.....
	57,600		144	0.6	.....
Minas Tecolotes.....	2,001,600 <sup>1</sup>	600	3,336 <sup>1</sup>	13.9	.....
	338,400		567	2.36	.....
Silver Lake.....	1,885,000	325	5,800	24.2	.....

IRON ORE WASHERY<sup>4</sup>

Oliver Iron .....	300,000 <sup>2</sup>	1,000 <sup>2</sup>	300	1.25	.....
Longdale Iron.....	1,144,800	480	2,385	10.0	.....

## MONTANA COPPER SULPHIDE MILLS

Anaconda.....	44,352,000	8,800	5,040	21.0	.....
Boston & Montana. .	25,000,000	3,000	8,300	34.6	.....

## UTAH COPPER SULPHIDE

Newhouse M. & S.....	1,440,000 <sup>1</sup>	1,000	1,440 <sup>1</sup>	6.0	} .....
	720,000		720	3.0	
Utah Copper Co....	8,640,000	6,000	1,440	6.0	.....

## NEVADA COPPER SULPHIDE

Giroux Con.....	800,000 <sup>1</sup>	800	1,000 <sup>1</sup>	4.0 <sup>1</sup>	} .....
	160,000		200	0.83	

## ARIZONA COPPER

Detroit Copper Min. Co.	275,000	1,100	250	1.04	.....
Old Dominion.....	750,000	500	1,500	6.26	.....

<sup>1</sup> In mill circulation. <sup>2</sup> Ten hours. <sup>3</sup> According to RICHARDS, the water used in stamping varies from 1 to 6.69 gal. per stamp per minute in the various mills under his observation, and 2.40 to 15.97 tons per ton of ore stamped. South African practice seems to be about 4 to 10 tons of water per ton of ore milled. <sup>4</sup> Log washers take about 2000 gal. of water per ton of ore in Southern practice.

## ADJUSTMENT, FEED AND CAPACITY OF MILL VANNERS

Abbreviations.—In = inches; R = round holes in stamp screens; Sq = square holes in stamp screens

Mill number.	Kind of vanner	Belt		Slope		Travel of belt, inches per minute	Num-ber of vibra-tions per minute	Feed		Tons treated by one vanner in 24 hours
		Kind	Width, feet	Life in months	Inches in 12 ft.	Degrees		Source	Maxi-mum size (d'), mm.	
18	Frue	Frue (b')	4*	..	6-7½	2°25'-2°50'	65½	(e)	..	..
19	Frue	Frue	4	24-36	5	2° 0'	..	(e)	..	..
20	Frue	Frue	4	12	..	..	190	(r)	..	..
24	Frue	Frue	4	24-60	2	0° 50'	24-36	(t)	..	..
26	Frue	Blaisdell	6	..	3	1° 12'	55	(c)	..	..
{	Johnston	..	..	..	4	1° 45'	..	(r)	..	4-6
	Woodbury (d')	Woodbury	5	..	4 4	2° 25'	230	(b)	..	4-6
{	Woodbury (d')	Woodbury	5	..	6 1	0° 35'	80	(w)	..	..
	Woodbury (d')	Woodbury	5	..	1½	0° 45'	76	..	..	..
{	Woodbury (d')	Woodbury	5	..	3 4	1° 20'	80	(k)	..	..
	Woodbury (d')	Woodbury	5	..	3.8	1° 30'	85	..	..	..
30	Frue	Blaisdell (b')	4	..	4	1° 35'	26	(w)	..	..
31	Frue	Frue (b')	4 & 6	..	3	1° 12'	36	(t)	..	..
32	Frue	Frue (b')	4	..	..	..	200	(f)	..	..
34	Frue	Frue (b')	4	..	..	..	190	(w)	..	..
35	Frue	Frue (b')	4	48	1½	0° 35'	(d')24	(e)	..	..
36	Frue	Frue (b')	4	..	..	..	215	(m) or (w)	..	..
37	Frue	Frue	4	..	..	..	..	(o)	..	..
38	Frue	Frue	6	..	..	..	..	(p)	..	..
39	Frue	Frue	4	54-60	3½	1° 20'	35-41	(w)	..	190-194
{	Frue	Frue	4	..	1½	0° 35'	46	(g)	..	..
	Frue	Frue	4	..	4.6	0° 50'	51	{ (g)	..	..
40	Frue	Frue (b')	4	60	3	1° 12'	36-48	(e)	..	204

41	Frue Tulloch	4	{ Canvas Rubber	{ 6 48 }	3½	1° 25'	36-72	200	(r)	.....	.....
43	Embrey Frue	5	(b')	.....	.....	.....	.....	.....	(w)(y)(j)	.....	.....
53	Frue Woodbury	4	Frue	.....	3½	1° 25'	48	160	(a)	0.70 Sq.	7¼
54	Frue Blaisdell (b')	5	Woodbury	.....	3½	1° 25'	48	235	(a)	.....	10¾
55	Frue Triumph	6	Blaisdell (b')	.....	4	1° 35'	35	200	(a)	.....	8½
57	Frue Triumph	6	Frue	.....	3	1° 12'	20	200	(a)	1.10 Sq.	4½
58	Frue Triumph	4	Smooth surface	.....	4	1° 35'	30	200	(a)	.....	.....
59	Frue Triumph	4	Blaisdell (c')	(c')	3	1° 12'	26	230	(a)	0.79 R.	4
60	Frue Triumph	4	Blaisdell (c)	120	2½	0° 54'	24	200	(a)	0.59 Sq.	5
61	Frue Triumph	5	Blaisdell (c)	24-30	2 3-23½	0° 55'-1° 5'	28	200	(a)	0.64 R.	3¾
62	Frue Triumph	4	Triumph	36	5¼	2° 5'	42-46	238	(a)	.....	4½
63	Frue Triumph	5	Woodbury	30	3	1° 12'	26	200	(a)	0.81 R.	15
64	Frue Triumph	4	Blaisdell (b')	.....	3¾	1° 30'	45	.....	(a)	.....	7½-10½
65	Frue Union	4	Blaisdell (b')	.....	5½	2° 20'	60	.....	(a)	0.75 R	5
68	Frue Frue	4	Frue	48	8.8	3° 30'	72	225	(a)	.....	7¾
69	Frue Frue	4	Blaisdell (b')	48	3¾	1° 30'	45	206	(a)	0.76 R.	12½
71	Frue Frue	4	Frue	48	5½	2° 10'	48	220	(a)	0.52 Sq.	4.4
72	Frue Frue	4	Blaisdell (b')	48	3-5	2° 15'	31	180	(a)	.....	0¾
73	Frue Frue	4	Blaisdell (b')	48	2½	1° 12'-2° 0'	36-72	190	(a)	.....	4
		4	Blaisdell (b')	48	5½	1° 0'	36-48	230	(a)	.....	12
		4	Frue	48	6½	2° 5'	30.6	168	(a)	.....	.....
		6	Frue	.....	3.6	2° 35'	36	171	(a)	.....	.....
		4	Frue	.....	3.6	1° 25'	22	196	(a)	.....	.....
		4	Frue	.....	3¾	1° 20'	55	216	(a)	.....	.....
		4	Frue	.....	4.2	1° 40'	63	206	(a)	.....	.....
		5	Frue	.....	3½	1° 25'	50	220	(a) (d)	.....	.....
		4	Frue	72	4½-5½	1° 47'-2° 5'	32-35	175-185	(a)	0.76 R.	12½

ADJUSTMENT, FEED AND CAPACITY OF MILL VANNERS. *Continued*

Mill number	Kind of vanner	Belt		Slope		Travel of belt, inches per minute	Num-ber of vibra-tions per minute	Feed		Tons treated by one vanner in 24 hours
		Kind	Width, feet	Life in months	Inches in 12 ft.	Degrees		Source	Maxi-mum size (a'), mm.	
74	Tulloch	Blaisdell (c')	3 3/4	.....	6 1/4	2° 35'	150	(a)	0.76 R.	12 1/2
75	Frue	Blaisdell (c')	4	.....	5 1/4	2° 5'	186	(a)	1 13 Sq.	9 3/4
76	Frue	(b')	6	60	4 1/4	1° 47'	188	(b)	.....	7 1/2-12 1/2
77	Gates	(b')	4	.....	18	7° 7'	224-240	(x)	.....	.....
78	Woodbury	Woodbury	.....	.....	.....	.....	.....	(x)	.....	.....
82	Frue	Frue	4	60	3	1° 12'	190	(a)	0.52 Sq.	5 1/2
83	Frue	Blaisdell (b')	6	.....	3	1° 12'	24-36	(a)	0.42 Sq.	10
84	Frue	Blaisdell (b')	6	.....	3	1° 12'	20-30	(a)	0.42 Sq.	7 1/2
85	Frue	Blaisdell (b')	6	.....	4	1° 35'	35	(a)	0.41 Sq.	12 1/2
86	Frue	Blaisdell (b')	6	.....	3	1° 12'	18	(a)	0.41 Sq.	5 3/4-6
87	Woodbury	Woodbury	5	.....	2 1/2-7	0° 55'-2° 45'	200	(a)	.....	.....
88	Woodbury	Woodbury	5	.....	4 2	1° 40'	223	(r)	.....	.....

<sup>1</sup> From R. H. RICHARD'S "Ore Dressing." The mill numbers refer to that book.

(a) Gravity stamps. (b) HUNTINGTON mill. (c) BAYAN mill. (d) GARFYN mill. (e) Spigots of whole current classifier. (f) Separate spigots of whole current classifier. (g) Spigots of No. 1 whole current classifier. (h) Spigots of No. 2 whole current classifier. (i) Spigots of No. 2 whole current classifier mixed with slime-table middlings. (m) First spigot of surface current classifier. (n) Second spigot of surface current classifier. (o) Second spigot of surface current classifier. (p) Second spigot of box classifier. (r) Overflow of hydraulic classifier. (s) Spigot of No. 2 hydraulic classifier. (t) Settling of finest jig. (u) Carpet-table tailings. (v) Slime-table middlings. (w) Slime-table heads. (y) Tailings of finest jig. (z) Preceding vanners. (a') These figures are the diameters of holes in the gravity-stamp screens when new. As the screens wear the size of particles will increase slightly. (b') Smooth surface. (c') Corrugated surface. (d') More or less. (e') Some more than 9 years, some less. (f') With seven belts. (h') With thirteen belts.

CANVAS, BLANKET AND CARPET TABLES

Kind of table	Length		Width		Slope		Life of surface	Feed	Destination of		Tons treated per table in 24 hr.
	Ft	In.	Ft.	In.	In. per ft.	Degrees			Clean- ing rates	Tail- ings	
Brussels carpet....	3	0	(v) 4	8	2 $\frac{1}{4}$	10° 35'	.....	(a)	(i)	(r)	10-15
Canvas.....	10	0	12	0	1 $\frac{1}{4}$	5° 55'	.....	(b)	.....	.....	7.5-12.5
Brussels carpet....	16	0	(v) 4	8	(h) 2	9° 30'	.....	(a)	(i)	(r)	5 $\frac{1}{2}$
Wool blanket.....	3	6	1	8	2	9° 30'	12 months	(b)	(k)	(s)	1.25
No. 6 cotton duck..	10	0	12	0	1 $\frac{1}{2}$	7° 5'	8 months	(b)	(m)	(s)	.....
No. 6 cotton duck..	10	0	12	0	1 $\frac{1}{8}$	5° 20'	8 months	(c)	(m)	(s)	.....
No. 6 cotton duck..	10	0	12	0	.....	.....	8 months	(d)	(m)	(s)	.....
No. 4 cotton duck..	39	6	1	8	7 $\frac{10}{34}$	3° 20'	.....	(e)	(m)	(s)	1.9
No. 4 cotton duck..	16	6	1	8	3 $\frac{1}{4}$	3° 25'	.....	(f)	(m)	(s)	.....
No. 8 cotton duck..	42	0	1	8	1 $\frac{1}{8}$	5° 20'	10 months	(g)	(o)	(t)	4.55

(a) Stamp pulp from amalgamated plates. (b) Overflow of hydraulic classifier. (c) Overflow of box classifier. (d) Tailings of special vanner. (e) Coarse riffle-box tailings. (f) Fine riffle-box tailings. (g) Vanner tailings. (h) Approximately. (i) Cleanup barrel. (k) Smeltery. (m) Special vanner. (o) Cyanide leaching. (r) Vanners. (s) Waste. (t) Arrastre. (v) Partitioned down the center.

**Water Used in Jigging**

According to RICHARDS, a jig will use anywhere from 0.528 to 22.22 gal. of water per square foot of jig area per minute, and from 8.76 to 54.98 tons of water per ton of ore in American practice, and 1.23 to 33.04 tons of water per ton of ore in European practice. The stroke of a jig varies from 1.63 to 7.18 times the diameter of the average grain fed to it. The coarser the grains the greater should be the throw, because coarse grains settle faster than fine grains and require a higher velocity of current and a greater quantity of water to lift them. The heavier the grains, the greater should be the stroke.

**Water Required in Milling**

(Data furnished by General Engineering Co.)

**Classifiers.** *Hydraulic.*—10–50 tons of water per ton of pulp.

**Jigs.**—18 × 36-in. compartment HARZ jigs, per compartment, 1½–2½ mm. particles, 2–4 gal. per min.; 3½–5 mm. particles, 5–7 gal. per min.; 7–10 mm., 8–14 gal.; 15–20 mm., 21–28 gal. per min. This is in addition to the water in the feed.

**Mills.** *Chile and Huntington.*—Crushing to 20 mesh, 5–6 tons of water per ton of ore passing the screens.

**Screens.** *Callow.*—24-in. duplex. Water in pulp, 3½–4 tons of water per ton of feed; spray water undersize, 6–10 gal. per min.; oversize, 8–12 gal. per min.

**Stamps.**—800–1000 lb. stamps, 3–6 gal. per min.

**Trommels.**—36 × 72-in., 1½–3½ mm. holes, 15–25 gal. per min.; 3½–7 mm. holes, 10–15 gal. per min.; 7–15 gal. per min., 5–8 gal. per min.

**Vanners.**—6 ft., 1½–3 gal. per min.

**Wilfley Tables.**—5–10 gal. per min.

**Water per Ton of Ore in Various Kinds of Mills**

- **Stamps and Vanners.**—20–30-mesh, 4–6 tons.
- Coarse Concentration.**—Rolls, jigs and tables, 15–20 tons.
- Combination Mills.**—Stamps, vanners and pans, 6–8 tons.
- Cyanide Mills.**—Shoveling tails and filter pressing, 0.2–0.35 tons.
- Cyanide Mills.**—Sluicing tailings, 1.3–1.9 tons.



LAUNDER GRADES  
(Washoe Concentrator, Anaconda, Mont. (*Eng. Min. Journ.*, Sept. 13, 1913, Vol. 96, p. 501))

	Size launder, in		Grade		Lining	Water ratio	Diam. largest part, mm.	Depth, str. m.	Percent. solid on 60 mesh	Slime
	Depth	Width	In	Per cent						
Undersize from round-hole trommel, $\frac{1}{8}$ in. . . . .	15	10	2	16 7	Cast iron	3.5	21	1 25	82	Present
Undersize from round-hole trommel, 5 mm. . . . .	7	8.5	3	25	Cast iron	5 2	5	1.25	75	Present
Undersize from round-hole trommel, 4 mm. . . . .	9 5	10 5	1.75	15	Cast iron	5	4	1 5	50	Present
Undersize from round-hole trommel, 2.5 mm	7	8.5	2.5	21	Cast iron	8 2	2 5	0.5	62	Present
Hutch product Harz jig. . .	7	6 5	1.0	8.3	Cast iron	22 7	6	1.0	95	None
Huntingdon mill feed. . . .	7	6	1.9	16	Cast iron	3 6	2	1.25	81	None
$\frac{3}{8}$ in conc. . . . .	10	9	1.3	11	Cast iron	12 8	7	1.0	100	None
Evans jig conc. . . . .	9 5	9.5	1.2	10	Cast iron	27 8	2	1.5	72 5	None
Coarse table. . . . .	7.5	7	1.2	10	None	14 2	0 3	0.5	7	Present
Fine feed. . . . .	5 5	4.5	1.2	10	None	13	0.2	0.75	0	Present
Table concs. . . . .	11	8.25	0.75	6.25	None	15 6	0.2	0.75	0	None
Table mid'd'g. . . . .	4 5	5	0.75	6.25	None	15 6	0.2	0.75	0	None
Table tail'g. . . . .	7	7.5	0.75	6.25	None	10 0	0 3	0.5	10	Little
*Secondary table. . . . .	7	7.5	1.2	10	None	7 4	0.9	0.5	44	None
*Primary, fine feed. . . . .	7	7.5	1.2	10	None	14 0	0.35	0.5	2	None
*Primary, coarse feed. . . .	7	7.5	1.2	10	None	4 4	0 9	0.5	46	None

\* Remodeled section.

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## LAUNDER GRADES

(Cananea Consolidated, Sonora, Mexico (TYE and COUNSELMAN, *Eng. Min. Journ.*, Vol 95, p. 375))

	Size launder, in.		Grade		Lining	Water ratio	Largest particle, mm.	Per cent. weight on 60 mesh		
	Depth	Width	Inch perft.	Per cent.						
Orig. feed; sec. C	10	12	3½	30	CI	1	30	82		
Bull jig tails. . . .	10	9½	3	25	CI	1.1	28	98		
Roll jig tails. . . .	10	7½	2¼	19	CI	3.	10	98		
Coarse jig conc. . .	10	7½	1.66	14	CI	2.9	35	95¹		
Undersize 2 mm. trommel. . . . .	10	5¾	1.5	12.5	CI	4.4	4	52¹		
First spigot classifier to sand jig	8	5¾	3	33	CI	1.5	4	90		
Shak. launder sand jig conc. . .	6½	12	¾	3	None	19	4	84		
Fine jig conc. . . .	10	7½	1.81	15	CI	6	4	80		
Chile mill discharge Drag	8¾	11½	2½	4.5	None	1.7	2.5	26		
belt from last	10	7½	1.66	14	CI	0.9	2.5	46		
First spigot classifier to mud jigs	8	5½	1.66	14	CI	17	3	60		
Table feed nos 27 to 30	7¼	5½	0.5	4	3	None	8.4	1	0.3	
Table conc. drag belt . . .	9½	9½	½	1	1½ in	26	1	13.6		
Table conc. shaking launder. . .	4	7½	0	1	0.75	7	4	0.5	35.2	
Slime, sec. C, settling tank to vanners B. . . . .	6½	9½	2½	4	5	None	96	0.17	0	
Slime feed to van. C. . . . .	9½	11½	½	2.75	None	4.7	0.17	0	5	
Van. conc. drag-belt launder	10×25×16		Level	0	None	31	0.2	1		
Vanner and table conc. . . . .	6½	6	1.94	16	None	20	2	27.2		
Vanner tails, sec C. . . . .	9½	11½	½	2	75	None	7	0.4	0	4
Coarse table and jig T. . . . .	9½	22	½	2.75	½ in. brd	27	2	41	6¹	
Coarse sand tail, dam 2. . . . .	12¼	11½	½	2	75	½ in. brd	21	2	19.5¹	
Coarse sand tail, dam 1	12	11	¾	4	5	brd	21	2	19.6¹	
Slime to mill 4. . . .	9½	12½	0	25	2	None	4.4	0.1	0	
Sand and slime to mill 3	10	11½	0	25	2	None	5	1.5	2.6	
Feed to vanners M. 4. . . . .	6	7½	½	2	75	None	4.4	0	1	0
Slime conc. M. 4 drag belt. . . . .	12×24×18		Level	0	None		0.1	0.2		
Slime conc. M. 4 elevator	7	7½	¾	5.5	Glass	20	0	1	0.4	
Slime conc. M. 3 elevator	10	12	0.94	8	Concrete	8.7	0.2	2.8		
Slime trail, mill 4 to settling tanks	10	11	0.22	1.83	None	6.3	0.1	0		

All cast iron liners 24 in long and 2 in. effective depth, corners rounded.

¹ These launders liable to choke. Glass liners 4 × 14 × ¾ in. Coarse sand has sp. gr 2.7, fine slime 2.8; pyrite 4.84; chalcocopyrite 4.17.

**QUANTITIES OF WATER FLOWING IN RECTANGULAR LAUNDERS  
OF ROUGH PLANK**

Depth of water in inches	Slope in 1 ft.				
	½ in.	¾ in.	1 in.	1 in.	2 in.
<b>GALLONS PER MINUTE, LAUNDERS 4 IN. WIDE</b>					
½	5.8	8.2	11.7	16.5	23.3
1	18.9	26.3	37.8	53.5	75.7
2	52.4	74.2	105.0	148.0	210.0
3	91.6	130.0	183.0	259.0	366.0
4	129.0	183.0	259.0	366.0	517.0
<b>LAUNDERS 8 IN. WIDE</b>					
1	42.1	59.5	84.2	119	168
2	129.0	189.0	259.0	366	517
3	240.0	339.0	479.0	676	958
4	363.0	519.0	726.0	1,027	1,452
6	625.0	884.0	1,250.0	1,767	2,500
8	890.0	1,253.0	1,779.0	2,516	3,558
<b>LAUNDERS 12 IN. WIDE</b>					
1	69.3	98	139	196	277
2	211.0	298	422	597	844
4	626.0	884	1,250	1,767	2,500
6	1099.0	1,554	2,198	3,108	4,396
9	1908.0	2,698	3,816	5,395	7,631
12	2736.0	3,868	5,471	7,736	10,943
<b>LAUNDERS 16 IN. WIDE</b>					
1	94	133	188	266	376
2	309	437	617	873	1,235
4	890	1,258	1,779	2,516	3,559
8	2,432	3,438	4,863	6,877	9,727
12	4,116	5,820	8,232	11,640	16,464
16	6,000	8,485	12,001	16,961	24,002
<b>LAUNDERS 32 IN. WIDE</b>					
1	196	278	393	556	786
2	650	919	1,301	1,839	2,601
4	2,075	2,933	4,149	5,167	8,298
8	8,000	8,435	12,001	16,969	24,002
16	16,023	22,657	32,046	45,313	64,092
24	26,751	37,826	53,503	75,653	107,005
32	38,590	54,565	77,179	109,131	154,358

CARKEEK'S<sup>1</sup> SLOPE FOR LAUNDERS<sup>1</sup>

Size of ore	Degrees	Slopes, inches per foot	
Mine ore to breaker.....	36° 35'	8.9	Dry.
2 in. to 1 in.....	37° 50'	9.33	Wet.
1 in. to ½ in.....	33° 40'	8.0	Wet.
½ in. to ¼ in.....	29° 5'	6.66	Wet.
¼ in. to ⅛ in.....	24° 0'	5.33	Wet.
⅛ in. to 1/16 in.....	18° 25'	4.0	Wet.
1/16 in. to vanner material...	7° 33'	1.6	Wet.
Table or vanner material...	6° 20'	1.33	Wet.
Tail race for 1/16-in. material...	3° 35'	0.75	Wet.
Tail race for 1/8-in. or larger....	6° 20'	1.33	Wet.
Trommel casing for - ½-in. material.....	16° 15'	3.5	Wet.
Trommel casing for + ½-in. material.....	33° 40'	8.0	Wet.

<sup>1</sup> R. H. RICHARDS, "Ore Dressing," Vol. II.Launder Grades<sup>1</sup>

## Mill Launder.

Mesh battery screen .....	10	14	20	25	32
Launder grade, per cent.....	7 5	6	5	4	3

**Battery Tables.**—1½ in. per ft. = 10.4 per cent.**Tube Mill Circuit.**—Underflow spitzlutte, shaking table, shaking table underflow 10 per cent.

## Cyanide Plant.

Per cent. of +60 mesh in pulp	Under 10	10-20	20-40	over 40
Of low-spitz launder, per cent.	3	3 25	3 5	4
Underflow of slime spitz ....	4.4	4 25	4 5	5
= sand pulp launder, per cent.				
Of low slime sp. = slime....	1.25 per cent. grade			
Of low return sand sp.....	1 per cent. grade			
Underflow return sand (fine sand).....	4			
Return water .....	1			
Solution pipes.....	1			

All launders should have corner pieces (45°) between sides and bottom. For curves add at least 1 per cent. to grades.  
Pipes should have grade enough to empty themselves without flushing.

<sup>1</sup> C O SCHMITT, *S African Metallurgy*, Vol. 1, p 187.

SPEED OF CURRENT NECESSARY TO<sup>\*</sup> MOVE DIFFERENT SIZES  
OF SAND AND PEBBLES

Material	Velocities at bottom of stream. <sup>1</sup> feet per second	
	Slowest observed velocity that moved the grains	Fastest observed velocity that did not move grains
Brown clay (sp. gr. 2.64).....	0 36	0 27
Fine sand (sp. gr. 2.64).....	0 62	0 53
Coarse sand.....	1 07	0 71
Gravel, size of anise seed . . . .	0 53	0 36
Gravel, size of peas or larger...	0 71	0 62
Gravel, size of common beans.	1 55	1 07
Beach pebbles, 1 in. or more.	3 20	2 13
Angular weather flint, egg size .	4 00	3 20

<sup>1</sup> R. H. RICHARDS, "Ore Dressing," Vol II.

PERCENTAGE OF MOISTURE RETAINED BY DIFFERENT SIZES OF  
ORE AFTER THOROUGH WETTING FOLLOWED BY REASON-  
ABLE DRAINING

Size, mm.	Material	Moisture, per cent <sup>1</sup>	Size, mm	Material	Moisture, per cent. <sup>2</sup>
64-32	Ore	0 35	4-3	{ Ore	5.66
32-22	Ore	0.55		{ Calcite	5.21
22-16	Ore	0.74	3-2	{ Ore	6.19
				{ Calcite	6.06
16-12	{ Ore	1.33	2-1	{ Ore	8.59
	{ Calcite	2.49		{ Calcite	9.30
			1-0.5	{ Ore	17.59
12- 8	{ Ore	2 25		{ Calcite	18.90
	{ Calcite	2 58	0.5-0.35	{ Ore	18.16
8- 6	{ Ore	3.01		{ Calcite	20.44
	{ Calcite	3.38	0.35-0.10	{ Ore	16.80
6- 4	{ Ore	2.91		{ Calcite	20.57
	{ Calcite	3.91	0.10-0	{ Ore	16.94
				{ Calcite	21.69

<sup>1</sup> R. H. RICHARDS, "Ore Dressing" vol. II.

<sup>2</sup> Percentage calculated on weight of mixture of pulp and water:

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## SPEED OF MINERAL GRAINS FALLING IN WATER (METERS PER SECOND)<sup>1</sup>

Diameter in mm.	Nature of grains	¼ sec.	¼ sec.	½ sec.	1 sec.	2 sec.
15	Galena	0.903	1.441	1.630	1.650	1.650
	Pyrates	0.825	1.174	1.287	1.293	1.293
	Quartz	0.570	0.767	0.801	0.817	0.817
4	Galena	0.704	0.814	0.823	0.824	0.824
	Pyrates	0.586	0.643	0.646	0.646	0.646
	Quartz	0.383	0.409	0.409	0.409	0.409
1	Galena	0.409	0.413	0.414	0.414	0.414
	Pyrates	0.321	0.323	0.323	0.323	0.323
	Quartz	0.203	0.204	0.204	0.204	0.204

<sup>1</sup>"Handbook of Milling Details," McGraw-Hill Book Company, Inc.

## SLOPE OF PLATES IN AUSTRALIAN MILLS<sup>1</sup>

Name of mill	Situation	Slope of plates, inches per foot	Water per battery per minute, gallons
New Star of the East.....	Ballarat	$\frac{7}{8}$	37½
Old Star of the East.....	Ballarat	$\frac{3}{4}$	37½
Britannia United.....	Ballarat	1	25
Harrierville.....	Ovens district	$\frac{7}{8}$	25
Oriental.....	Ovens district	$\frac{3}{4}$	20
Old Fortuna .....	Bendigo	$1\frac{5}{16}$	.....
New Fortuna.....	Bendigo	$1\frac{1}{8}$	.....
Pearl.....	Bendigo	$1\frac{3}{4}$	32½
New Chum Consolidated.....	Bendigo	$1\frac{1}{4}$	.....

<sup>1</sup>R. H. RICHARDS, "Ore Dressing," Vol II.

UNITED EASTERN MINING Co.—ANALYSIS OF MILLING COSTS  
(For the Year 1926)

	Labor	Supplies	Power	Miscellaneous	Amount		Cost per ton	
					1921	1920	1921	1920
General.....	\$10,204 35	\$ 3,207 91	\$ 551 45	\$ 2,655 55	\$ 16,619 26	\$ 17,140 71	\$0 171	\$0 166
Lighting expense.....	55 35	178 19	278 57	.....	512 11	362 62	0 005	0 004
Water supply.....	3,928 77	2,358 00	2,318 20	5 58	8,610 55	10,871 28	0 088	0 106
Coarse crushing.....	2,751 49	1,845 97	1,139 46	0 27	5,737 19	5,520 26	0 059	0 054
Coarse grinding.....	4,712 65	10,318 00	17,992 49	.....	33,023 14	39,662 54	0 339	0 385
Fine grinding.....	7,173 68	15,398 58	23,620 95	.....	46,193 21	46,575 17	0 474	0 452
Cyaniding.....	8,912 44	25,879 27	16,598 16	.....	51,390 18	51,878 23	0 528	0 503
Tailing disposal.....	1,909 50	7 72	.....	0 31	1,908 22	5,407 46	0 020	0 053
Clarification.....	103 82	1,578 84	1,032 32	.....	2,714 98	3,358 58	0 028	0 033
Precipitation.....	511 25	5,497 98	2,165 03	.....	8,174 26	8,400 10	0 084	0 082
Refining.....	3,054 98	4,100 26	277 19	.....	7,432 43	7,432 54	0 076	0 072
Sampling.....	2 89	258 92	67 38	.....	329 19	155 03	0 004	0 005
Assaying.....	2,334 18	962 22	507 51	12 63	3,186 54	3,411 52	0 039	0 033
Retreating tailing.....	1,425 67	31 05	.....	18 43	1,475 15	2,184 41	0 004	0 021
Mill heating.....	238 02	1,731 08	.....	0 55	1,969 65	4,156 37	0 020	0 040
Solution recovery.....	208 21	69 87	512 31	.....	790 39	-1,755 72	0 008	0 017
Experimental.....	7 99	26 14	.....	89 00	123 13	.....	0 001	.....
Total milling, 1921.....	\$47,526 24	\$73,540 00	\$67,061 02	\$ 2,782 32	\$190,819 58	.....	\$1 948	.....
Total milling, 1920.....	52,450 70	74,362 86	61,734 42	19,719 56	.....	\$208,267 54	.....	\$2 023
Cost per ton, 1921.....	0 477	0 754	0 688	0 029	1 948	.....	.....	.....
Cost per ton, 1920.....	0 509	0 722	0 600	0 192	2 023	.....	.....	.....
Tons.....	.....	.....	.....	97 413	99 225	.....	.....	.....
Value per ton.....	.....	.....	.....	\$ 20 26	\$ 21 76	.....	.....	.....
Recovery.....	.....	.....	.....	96 23 %	97 95 %	.....	.....	.....

**Wisconsin Roasting and Magnetic Separating Costs, 1921**COSTS PER TON OF GREEN ORE ROASTED, BASED ON A  
TONNAGE OF 125 TONS PER 24 HOURS

<b>Roasting and separating:</b>	
Labor.....	\$0.70
Power.....	.43
Repairs and supplies.....	.15
<b>Total.....</b>	<b>\$1.28</b>
<b>Ore receiving and shipping:</b>	
Labor.....	0.18
Ore freight.....	.50
Power.....	.05
Repairs and supplies.....	.06
Assaying.....	.12
<b>Total.....</b>	<b>.91</b>
<b>Cottrell electric precipitator:</b>	
Labor.....	0.06
Power.....	.11
Repairs and supplies.....	.01
<b>Total.....</b>	<b>.18</b>
<b>General:</b>	
Overhead.....	0.25
Office expense.....	.20
Insurance, taxes, etc.....	.01
Workmen's compensation insurance.....	.01
Freight and express.....	.03
Experimental.....	.03
Labor.....	.06
Repairs and supplies.....	.04
<b>Total.....</b>	<b>.63</b>
<b>Total cost.....</b>	<b>\$3.00</b>

**Roasting and Gravity Treatment for Lead Ores<sup>1</sup>**

Certain oxidized lead ores become amenable to gravity separation after roasting. These are ores in which the lead exists largely as lead carbonate and the gangue is composed largely of siliceous or limey material. Oxidized ores that contain considerable zinc as smithsonite ( $\text{ZnCO}_3$ ) also yield to this treatment.

Complete conversion of the carbonate to oxide takes place in about 1 hr. at between 450 and 500°C., and increases the specific gravity of the lead mineral sufficiently to give an effective increase in recovery. Above 500°C. lead silicates begin to form preventing good extraction of the lead.

**Milling Practice in the Coeur d' Alenes, 1927**

In a general review of the subject of milling practice in the Coeur d'Alene District, in 1927, A. W. FAHRENWALD states that on complex ores flotation has largely superseded tabling. The

<sup>1</sup> MILLER and HEAD, *Tech. Paper* 413, U. S. Bur. Mines, "Roasting of Lead-carbonate Ores Preliminary to Gravity Concentration."



accompanying tables on pp. 500-503, show the trend of practice there.<sup>1</sup>

In comment on these tables FAHRENWALD says that in the past poor quality of ore dressing was due to insufficient pulverization than to any other factor. Microscopic examination of the middlings (cleaner tails) shows locking of minerals at sizes finer than 500 mesh.

In all the plants the ball mills are operated in close circuit with Dorr or drag classifiers. The Esperanza type of classifier is popular because of low first cost, but the Dorr is probably more efficient.

Grinding in the ball mill is done at a pulp dilution of about 70 per cent. solids. The author states both laboratory and mill experiments show the best dilution at from 25 to 33 per cent. moisture. The cost of fine grinding runs from 20 to 30¢ per ton of original ore crushed.

Minerals Separation "Sub A," O & D, and the FAHRENWALD flotation machines are used in the district. Old type CALLOW and HEARING cells are used as cleaners in some mills. The trend is decidedly toward multiple cell vertical shaft and impeller machines.

<sup>1</sup> From a paper presented at the Salt Lake Meeting, A. I. M. E., August, 1927.

PRINCIPAL OPERATING COMPANIES<sup>1</sup> IN THE COEUR D'ALENE DISTRICT, IDAHO; NATURE OF THE ORE MILLED AND MILLING METHODS

Company	Name of mill	Mill reference No.	Nature of ore		Milling method
			Ore minerals	Gangue minerals	
Hecla Mining Co. . . . .	Old mill at Gem	1	Argentiferous galena	Quartz, quartzite and siderite	Jigs, tables and flotation. Lead concentrate made.
Hecla Mining Co. . . . .	Jig tailing flotation mill	2	Argentiferous galena	Quartz, quartzite and siderite	All flotation. Lead concentrate made.
Callahan Zinc-lead Co. . . . .	Galena mill	3	Galena, tetrahedrite, sphalerite, and pyrite	Quartz, quartzite and siderite	All flotation. Lead concentrate made.
Federal Mining & Smelting Co. . . . .	Morning mill	4	Galena and sphalerite, both silver-bearing	Siderite and quartzite	All flotation. Lead and zinc concentrates.
Federal Mining & Smelting Co. . . . .	Page mill	5	Galena and sphalerite, both silver-bearing	Quartzite gangue and some siderite	All flotation. Lead and zinc concentrates.
Bunker Hill & Sullivan Mining & Concentrating Co.	Old West mill	6	Argentiferous galena	Quartzite and siderite	Jigs, tables and vanners and flotation. Lead concentrate made.
Bunker Hill & Sullivan Mining & Concentrating Co.	South mill	7	Galena and sphalerite	Quartzite, siderite and some pyrite	Jigs, making waste, otherwise all flotation. Lead and zinc concentrates.
Bunker Hill & Sullivan Mining & Concentrating Co.	El Hembra	8	Lead-silver antimonial ore	Quartzite and iron minerals	All flotation. High silver concentrate.
Bunker Hill & Sullivan Mining & Concentrating Co.	Sweeney mill	9	Galena and sphalerite	Quartz and quartzite	Same as 7.
Hays Co. . . . .	Hays mill	10	Galena-silver old Bunker Hill River bed tailings	Quartzite and siderite badly decomposed and polluted with organic matter	All flotation. Lead-silver concentrate.
Constitution Mining & Milling Co.	Mill on Pine Creek	11	Galena and sphalerite, and some pyrite	Quartz, quartzite slate and gangue	All flotation. Bulk lead-zinc concentrates.
Hercules Mining Co. . . . .	Old mill rebuilt for crushing	12	Argentiferous galena and sphalerite	Quartz, quartzite, some magnetite, pyrite	Tables, but chiefly flotation. Lead and zinc

Tamarack & Custer Consolidated Mining Co.	tom flotation	13	Galena, sphalerite	rite, and siderite Quartz, quartzite, siderite, magnetite, pyrite Quartzite	concentrates. Jigs, tables and flotation. Lead and zinc concentrates. All flotation. Copper concentrate.
Ore-Idaho Mining & Milling Co.	Snow storm	14	Chalcocite, bornite and chalcopyrite	Quartzite	
Highland Surprise Mining Co.	Mill on Pine Creek	15	Galena and sphalerite	Quartz, quartzite, slate, pyrite	
Hull Leasing Co.	Mill at Gem	16	Galena and sphalerite	Quartz, quartzite, siderite	
Jack Waite Co.	.....	17			All flotation. Lead and zinc concentrates.

<sup>1</sup> Several small companies are not included, and two new modern mills are in course of design.

## FINE GRINDING PRACTICE IN THE COEUR D'ALENE, IDAHO, FLOTATION PLANTS

Mill number	Ball mill		Feed maximum size	Solids in mill discharge per cent.	Circulating load, percentage of original feed	Tons per day	Classifier		
	Name	Units	Size				Make and size	Dragover mesh and per cent.	Overflow (floatation feed) mesh and per cent.
1	C & W Hardinge	1	5 by 6 ft.	7 mm. 16 in.	300	800	Drag 4 ft. by 6 in by 18 ft. Dorr duplex	C & W mill -2 mm. round hole screen Hardinge 10% +200 + 8-3.5%; + 14-9.8% + 28-25.4; + 48-39.8 + 65-10.9; + 100-3.4 + 200-2.7; -200 3.8	+ 48-3.5% + 65-11.0 + 100-15.0 + 200-18.0 -200-52.0
2	Hardinge	3	8 ft. by 36 in						
3	Hardinge	1	8 ft. by 22 in.	70	500	150	6 ft. by 20 ft. Dorr duplex	+ 8-3.0%; + 14-4.1% + 28-6.2; + 48-10.1 + 65-21.2; + 100-25.0 + 200-26.0; -200-4.4	-200-10%
4	Hardinge ball Hardinge pebble	4 2	8 ft. by 36 in. 8 ft. by 36 in.	80	400	1200	Drag double belt	+ 8-0.5%; + 14-2.0% + 20-2.0; + 28-6.6 + 35-13.2; + 48-13.4 + 65-20.5; + 100-20.5 + 150-8.8; + 200-4.1; -200-7.4	
5	Hardinge	1	8 ft. by 36 in.	80	400	275	Drag double belt	Not available	Not available
6	Hardinge		6 ft. by 22 in.	23					

7	Hardinge	3	6 ft. by 22 in.	— 7 mm.	50	300	Eperanza and Fahrenwald	Eperanza + 20—0.4%; + 65—38.8% + 100—20.3; + 150—19.7 minus 200—20.8	Eperanza —150—99 0%
9	Hardinge Hardinge	1 1	8 ft. by 30 in. 6 ft. by 22 in.	— $\frac{1}{4}$ in. —20 mesh	50	200			
11	Hardinge P & M	1 2	6 ft. by 22 in. 5 ft. by 5 in.	— $\frac{3}{4}$ in.	60	300	Drag felt type	NOTE: Double classification practiced. Overflow from closed circuit classifier goes to second classification	Overflow second classification +100—1.8% +140—2.0; +170— 4.7 +200—1.6; —200— 89.9
12	P & M	1	7 ft. by 7 ft.	— $\frac{1}{2}$ in.	.	250 to 300	Drag		+ 48—1.7% + 65—6.7; + 80—2.0 + 100—8.3; —100— 81.3 to 90
14	Hardinge	1	6 ft. by 22 in.	— $\frac{1}{4}$ in.	70	80			

## FLOTATION

### Flotation Processes

**Crilley and Everson.**—The ore is crushed to 50 mesh, and mixed with a thick black oil. Boiling water containing enough acid to give it a tart taste is then added. This process was tried at Baker City, Ore., and at Denver, in 1889.

**Robson and Crowder.**—The ore was mixed with but little water, 25 to 30 per cent., agitated and oil added during agitation. This was operated at the Glasdir mine in Wales, in 1894.

**Elmore (Old Process).**—The ore was mixed with several times its weight of water, and an equal, or greater weight of oil in a revolving drum. The oil was mixed without emulsifying, then run on a spitzkasten, where the oil carried the sulphides to the surface, and the gangue and water were removed from the bottom. This process was invented in 1898 and tried extensively. Its history may be said to close in 1905.

**Potter-Delprat.**—The original POTTER process (1902) was one of flotation in a 1 to 10 per cent. acid solution. The mixture was 1:1 of ore and acid solution; this was agitated freely and heat applied, causing the forming of CO<sub>2</sub> from the carbonates in the ore. This caused the sulphides to rise to the surface where they were either allowed to flow off continuously or were skimmed off. This was clearly a surface tension process. DELPRAT (1902) accomplished the same thing with acid salt-cake solution. Both processes were tried out at Broken Hill, Australia. Later patents indicate that oil has been found to assist in this process. These inventors worked independently, became involved in litigation and eventually pooled their interests.

**Froment.**—ALCIDE FROMENT discovered in 1901 that when a sulphide ore is agitated in water with a little oil and sulphuric acid, the sulphide particles become oiled and attach themselves to and are floated by gas bubbles. He recommended adding a little calcite to the ores when needed. Minerals Separation, Ltd., bought this patent in 1903.

• **Minerals Separation, Ltd.**—Organized in 1903 by BALLOT, CURLE, WEBSTER, GREGORY, SULMAN and PICKARD to acquire the CATTERMOLLE patents. Soon after bought the FROMENT patents. Present processes are based on surface-tension phenomena, accelerated by means of addition to the pulp of small quantities of oil and air in minute subdivision. There is only about 0.1 per cent. oil added, and very violent agitation is indulged in for from 1 to 10 minutes. Innumerable small bubbles of air are thus mechanically introduced which join the oil-coated particles. These are then removed on a spitzkasten. Exposure to air after this treatment then aerates any mineral which has not already taken up its oil film after which a second spitzkasten treatment removes this.

<sup>1</sup> From HOOVER'S "Concentrating Ores by Flotation," *The Mining Magazine*, London.

**Cattermole.**—Added 4 to 6 per cent. of oil, according to the sulphide contents, to a freely flowing pulp, and also 2 per cent. of soap. This process was bought up by Minerals Separation, Ltd.

**Goyder and Laughton.**—Their process (1905) was only a variation of the POTTER-DELPAT. It was used at Broken Hill.

**Wolf.**—JACOB D. WOLF in 1903 invented a method of applying the principles of flotation. He used sulpho-chlorinated or other oils and aimed to secure a high extraction with a low grade of concentrate in the first step, and by washing with hot water to concentrate the concentrate in a second step. Apparently no commercial use was made of it.

**Elmore (Vacuum Process).**—In 1904 FRANCIS E. ELMORE took out patents covering a process in which flotation is secured by the addition of a small quantity of oil, and by the liberation of air in the pulp in a finely divided condition, this being accomplished by subjecting the freely flowing pulp to a vacuum and simultaneous heating.

**De Bavay.**—AUGUSTE J. F. DE BAVAY in 1904 invented a flotation process in which a freely flowing pulp was brought to the surface of a vessel of water, where advantage was taken of the surface tension of the liquid, and the sulphide floated. A film of carbonate on the sulphide, from weathering, is detrimental, and is removed by soaking the ore in a weak solution of carbonate of ammonia, or by passing carbon dioxide through the pulverized wet ore, or by friction. In the original process no oil or acid was used. Later these were also made use of.

**Macquisten.**—ARTHUR P. S. MACQUISTEN, in 1904, invented a process and a tube apparatus for floating sulphides by surface tension. Oil has since been added to the process. It is operating at the Morning mill at Mullan, Idaho.

**Zinc Corporation.**—Organized in 1905 to treat zinc tailing in the Broken Hill district. Tried POTTER process in 1905. Remodeled plant in 1907 for Minerals Separation process. In late 1907 and 1908 built an ELMORE vacuum mill. In 1910 again adopted Minerals Separation.

**Hyde.**—In 1911 JAMES M. HYDE patented a process in which a small amount of sulphuric acid, with or without the use of copperas, is used to give the slimy portion of the ore a preliminary coagulation before flotation. The sulphides, after agitation, are floated off rapidly and as completely as possible with a considerable overflow of freely flowing water, thereby producing an impure concentrate which is re-treated in a second machine. At present the process is being used by the Butte & Superior Copper Co. It was in litigation with Minerals Separation, Ltd.

**Murex.**—While this process is not strictly of the same class as the others, it still makes use of the principle of selective oiling of sulphide particles. In this process the crushed ore is fed into an agitator and mixed with 4 to 5 per cent. of its weight of a paste made of 1 part of oil or thin tar with 3 or 4 parts of

magnetic oxide of iron.<sup>1</sup> This oxide must be ground to an impalpable powder. These ingredients, with enough water to make a pulp, are agitated from 5 to 20 minutes. The paste preferentially adheres to the sulphides because of the oil. The ore is then fed over magnets and the oxide of iron, with the mineral adhering to it, pulled out. The oil and magnetite are then recovered.

**Sanders.**—This process uses, instead of an acid bath in deep pans, a dilute solution of aluminum sulphate in shallow pans. It was tried by the Tri-Bullion Smelting & Development Co. on a commercial scale, without success.

**Horwood.**—If a mixture of iron, copper, lead and zinc sulphides is roasted, the three former can be changed to oxide and sulphide at a comparatively low temperature, whereas the blende is practically unaltered. The partly roasted material is then subjected to a heated-acid oil-flotation process, by which the zinc is floated, the other metals staying behind.

**Lyster Process.**—Apparently JAMES LYSTER of the Zinc Corporation, Ltd., was the inventor of the first successful selective flotation process.

## THE FLOTATION PROCESS<sup>1</sup>

**Definition of Flotation.**—Where finely divided ore is agitated in water with a gas and one or more other reagents, one of which is usually an oil, it will be found that certain minerals rise in a froth to the top of the solution, while others do not. Those which rise are "floatable."

Ordinarily, those which rise are sulphides, arsenides, or the like, but graphite, sulphur, and mica do also, while phosphate rock has recently been floated. If the ore is ground finely enough to unlock all the particles of different composition, without too great sliming, a complete separation of minerals can thus be effected.

No matter how the gas is introduced, by impellers, through a porous diaphragm, or otherwise, it must be finely divided and thoroughly disseminated through the water and ore, so that all of the floatable mineral may come in contact with it.

**Reagents.**—The reagents added are of various sorts and have various functions. Some lower the surface tension of the water, thus promoting the formation of a stable froth. Some clean the surface of the mineral or produce other desirable changes in the ore or destroy interfering reagents. Others, the oils (usually) attach themselves to the mineral particles (collectors). We thus have frothing, collecting, accelerating, antitoxic, conditioning, decadening, deflocculating and flocculating, neutralizing, depressing, inhibiting, modifying, promoting, reactivating, retarding, selecting, sickening or toxic agents. Some will fulfill two functions.

<sup>1</sup> Much of the following pages is based on WEINIG and PALMER's "Trend of Flotation," *Colo. School of Mines Quarterly*, April, 1928.



Flotation may be either "bulk," in which all the floatable minerals are lifted, or "selective," where first one, then another, is floated; or selective flotation may be used to treat the product from bulk flotation.

**Theory of Flotation.**—Adsorption by the particles to be floated of the collecting agent seems to be the chief explanation of the phenomenon. This adsorption appears to precede chemical changes in the particle. In general, the selectivity of this adsorption appears to follow SCHÜRMAN's series (*cf. p. 717*), those sulphides that are most readily formed being the most floatable.

**Frothing Agents.**—These are usually oils from the distillation of wood or coal. Steam-distilled pine oil is the most common. Pine tars, wood tars, coal tars, creosote and its derivatives have all been used. A frothing agent must be soluble in order to affect the surface tension of the water.

**Collecting Agents.**—A number of organic compounds containing sulphur are currently used for this purpose, such as alkaline xanthates and thiocarbonaldid. They are strongly adsorbed by sulphide minerals and increase the tendency of the latter to attach themselves to the oily bubbles. Some of the newer agents, such as phosphocresylic acid have strongly selective actions.

**Alkalis.**—Alkalis perform several distinct functions in flotation. They neutralize free acids, and they precipitate many soluble metal salts, such as iron sulphate, manganese sulphate and the like. These compounds are adsorbed by mineral particles, which increases the tendency to be wetted by water, hence to float less readily. They act as inhibiting agents toward the less readily floatable minerals, probably by formation of films of basic salts on their surfaces. They also act as clarifying agents to hasten the settling of finely divided gangue particles.

While lime is the cheapest alkali, in large quantities it inhibits the flotation of all sulphides, and for this reason is not used in zinc-lead separations where the mill water is reused. If originally used to depress the pyrite in the zinc-iron separation it would later interfere with galena flotation.\* Disodium phosphate is also used as an alkali, but is very expensive.

**Alkaline Sulphides and Polysulphides.**—These are used mainly in the flotation of oxidized ores to produce films of sulphides on the oxidized mineral. An excess of them interferes with the flotation of sulphide ores.

**Copper Sulphate.**—This is a reactivating agent and is the standard reagent for floating zinc sulphide that has been previously depressed.

**Sodium cyanide** prevents the floating of zinc and iron minerals. Its use is patented. (U. S. patents 1,421,585 and 1,427,235, 1922.)

**Sodium Sulphite.**—It is used as an inhibiting agent for zinc and iron minerals in their separation from galena.

**Zinc Sulphate.**—This salt is used as a retarding agent for zinc and iron minerals. It is usually used with cyanide, unless there is gold present that might be dissolved.

**Sodium Silicate.**—This compound promotes the formation of a brittle froth carrying a low percentage of insoluble gangue. It is a deflocculating agent on gangue particles, but flocculates sulphides in oxidized ores. It tends to revive slightly tarnished sulphide particles.

**Xanthates.**—The potassium and sodium salts are widely used as collectors. They can be prepared by treating alcohol with molecular equivalents of carbon disulphide and sodium or potassium hydroxide. Xanthates deteriorate on heating. The smallest amount of lime is used with xanthates that will show alkalinity with phenolphthalein.

At Inspiration about 0.0045 lb. lime and 0.15 lb. xanthate solution (0.02 lb. xanthate crystals) and 0.14 lb. pine oil are used per ton of ore. Too much xanthate floats pyrite.

**Thiocarbanalid.**—This is also a collector. Because of its small solubility in water it is used in a solution of one part of thiocarbanalid in four parts of orthotoluidin. (The solution is known as T.T. mixture.)

**P.E. Oil.**—A blend of petroleum products used as a collecting agent. In connecting with pine oil it produces small bubbles and a brittle froth.

**ZI.**—Potassium xanthate.

**T.T. Mixture.**—One part of thiocarbanalid in four parts orthotoluidin. Collector.

**Zinc Sulphate.**—Depresses sphalerite.

**Aerofloat.**—Phosphocresylic acid—a basic collector and frother.

**A.T. Mixture.**—20 per cent. aniline and 80 per cent. thiocarbanalid. Collector.

**X-Y Mixture.**—60 per cent. alpha naphthol amine and 40 per cent. xylidine. Collector.

**N.T.U. Oil.**—An oil shale distillation product.

**Aldol.**—2-hydroxybutyraldehyde. Collector.

**Fumol.**—Collector. Same as aldol, 2-hydroxybutyraldehyde.

**Aerofloat or Phosphocresylic Acid.**—A reagent invented by F. T. WHITWORTH (U. S. Patent 1,593,232), made by treating cresylic acid with phosphorus pentasulphide. Its sale is controlled by the American Cyanamid Co. which gives a shop-right to purchasers. It is much used in the selective flotation of copper, lead, and zinc minerals as it promotes their flotation and has little effect on pyrite in alkaline circuits.

**Sodium Bichromate.**—An oxidizing agent used in the flotation of lead-zinc-iron sulphides. It is a depressant for pyrite, pyrrhotite, and galena. It is also used to correct an overoiled condition of de-leaded pulp before floating zinc.

**Sulphuric Acid and Acid Sludge.**—Formerly used to clean tarnished ores prior to bulk flotation. Sulphuric acid is still used to float pyrite and pyrrhotite that have been depressed temporarily by lime or cyanide.

Selective Zinc-lead Flotation<sup>3</sup> at Tootle, Utah

The concentrator is divided into two sections; one for the treatment of Park City ores, the other for the treatment of Bingham ores. The ores of both sections are crushed to  $-1\frac{1}{4}$  in. and are then ground in ball mills in circuit with a classifier. The first classifier overflow is divided between two secondary classifiers, each in circuit with a ball mill. The secondary classifier overflow is the flotation feed. Manganese steel liners and 4-in. forged steel balls are used in the primary ball mills. Hard white-iron liners and 2-in. cast-iron balls are used in the secondary mills. Pulp densities are held as close as possible in the primary mills to 72 per cent. solids, and to 68 per cent. solids in the secondary mills. The second classifier overflow (flotation feed) ranges from 22 to 24 per cent. solids. A typical screen analysis follows;

Screen size	Per cent. by weight
+65	1.6
-65 + 100	5.6
-100 + 150	7.6
-150 + 200	14.8
- 200	70.4
	<u>100.0</u>

	Section I	Section II
Lead roughers . . . . .	Minerals Sep.	Sub. A machines
Zinc roughers . . . . .	M. S. Sub. A	Callow pneumatic
Iron roughers . . . . .	Callow pneumatic	
Lead cleaners . . . . .	Callow pneumatic	
Zinc cleaners. . . . .	Callow pneumatic	
Iron cleaners. . . . .	Callow pneumatic	

The minerals separation cells are all of 18-in. double-disk agitator cells.

The CALLOW cells are all of the 3 × 3-ft. pan type. In both circuits a concentrate and a middling is taken from each rougher. The concentrate is cleaned and the cleaner tailings are taken back to the head of the circuit. Air is used in the CALLOW machines at  $4\frac{1}{2}$  lb. per sq. in.; in the Minerals Separation cells at 1 lb. per sq. in.

Soda ash is used as the alkaline conditioning agent in both lead and zinc circuits. With ores of the Bingham type as high as five pounds per ton of ore may be used in the lead circuit; seldom any additional in the zinc circuit. With ores of the Park City type little is required for the lead circuit; but from 2 to  $3\frac{1}{2}$  lb. per ton of ore is required in the zinc circuit.

Thiocarbamid is used as the basic lead collector. About 0.10 lb. per ton is used, for while not necessary, its use tends to stabilize collecting conditions and increase lead recovery.

*Sodium cyanide* is used as a lead accelerant and as a zinc-iron depressant. It is always used in conjunction with zinc sulphate and is added in the primary ball mill. Park City ores generally require 0.3 to 0.4 lb. sodium cyanide per ton; the Bingham ores, although having a higher iron content require less—0.20 to 0.30 lb. per ton.

*Zinc sulphate* is used as a depressant in conjunction with sodium cyanide and is added in the primary mills. From 0.6 to 1.2 lb. per ton of ore is required.

*Potassium ethyl xanthate* is used as an auxiliary collector in both the lead and zinc circuits, and is the only collector added to the iron circuits. The reagent has been found very beneficial, but must be held at a minimum to insure selectivity.

*Copper sulphate* is used as an accelerant in the zinc circuit, 0.7 to 1.5 lb. of crystals per ton of ore being added to the lead rougher tailing.

Aërofloat or phosphoresylic acid is used as the basic collector and frother in the zinc circuits, 0.15 lb. per ton of ore being added to the lead tailing.

*Steam* is added to the lead rougher tailing ahead of the zinc circuits, and the pulp heated to 30°, resulting in a marked improvement in the grade and recovery of zinc.

## ASSAYS OF FEED AND PRODUCTS

(Section I)

	Pb,	Ag, oz. p.t.	Au, oz p t.	Insol, %	Fe, %	Zn %
Feed. . . .	2.9	8.33	0.10		9.3	10.3
Lead conc	65.3	140.61	0.787	2.0	3.3	7.1
Zinc conc	0.9	7.10	0.40	1.9	2.7	59.1
Iron conc	1.5	6.64	0.16	8.6	36.9	4.3
Tailing	0.2	1.53	0.045		8.3	0.4

(Section II)

Feed	8.6	5.12	0.05		10.9	7.1
Lead conc	66.4	35.57	0.10	2.4	2.4	5.6
Zinc conc	2.7	2.16	0.04	1.9	1.6	59.8
Iron conc	5.0	6.16	0.14	9.3	34.8	2.7
Tailing	0.4	0.58	0.025		10.0	0.2

*Eng. and Min. Journ.*, Aug. 24, 1929.

## Breaking Up the Froth

The handling of froth concentrates has proved a serious problem for many operators when the froth has been tough and permanent. The most common method of breaking froth is by jets or sprays of water. A single strong jet of water turned on the flowing froth in a launder often results in material benefit,

and a water pipe perforated with many holes to give more jets is better, while special sprays, such as rotating garden sprays (inverted), Buffalo sprays, etc., prove even more efficient. Direct feed into a filter of the pressure-filter type is most efficient, as the froth does not need to be broken up. The vacuum filters are not so well adapted to immediate treatment of the froth because it generally is too thin (25 per cent. to 35 per cent. solids) to cake well; vacuum filters of the Portland or OLIVER type require approximately 50 per cent. solids in the pulp. However, by breaking the froth and dewatering, a vacuum filter is permissible. In a number of installations a bucket elevator seems to break up the froth to a satisfactory extent, actual tests made by one company indicating 80 per cent. efficiency in breaking froth, merely in the passage of the froth through the bucket elevator. Addition of chemicals, such as acid or lime, or of more oil to the froth, also tends to break it down and make the solids settle out well. If lime be used for this purpose, the mill water cannot be used again without neutralizing.

Settling of froth in bins for dewatering, while a common practice, is not satisfactory, as it practically imposes a canvas lining for the car in which the concentrates are shipped, and concentrates shipped in this manner will drain in such a "traveling filter" to about 25 per cent. or 30 per cent. moisture. In case of a long haul, this is expensive both in freight and leaks. Filters are being used in nearly all of the larger plants. OLIVER and Portland filters turn out a satisfactory product with 10 per cent. to 15 per cent. moisture, and pressure filters like the KELLY while more cumbersome and expensive to operate, are giving products ranging from 6 per cent. to 10 per cent. moisture.

Flotation costs—tailings treatment—Hecla mill, 1927—Labor, \$0.087; supplies (balls and liners), 0.085; flotation reagents and supplies, 0.013; power, 0.065; flotation royalty, 0.042; total, \$0.292. (W. J. ZEIGLER, Salt Lake City meeting, A.I.M.E., 1927). About 750 tons per day treated.

### pH Control in Flotation

At the Chief Consolidated mill at Eureka, Utah, flotation of oxidized ores by "natural" float was tried, *i.e.*, instead of sulphidizing the minerals, reagents to float the unaltered oxidized mineral were added. The pulp was conditioned with sodium silicate to promote a gangue dispersion in water, and aërofloat and ethyl xanthate were then added as flotation agents. Amounts used were 3 lb. sodium-silicate solution, 0.6 lb. aërofloat and 5.0 lb. ethyl xanthate. Mill results did not bear out laboratory tests and the difference was found to lie in a greater degree of acidity developed in the laboratory grinding from that developed in the mill. This was corrected with sulphuric acid and results improved. The optimum results were obtained with ball mill pH at 6.8 to 7.0; primary flotation cells at 7.0; and in the scavenger cells where ethyl xanthate was

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added, at 7.2. Froth from the scavenger cells was returned to the primary cells for cleaning (G. H. WIGTON, *Min. Met.*, December, 1928).

A. M. GAUDIN states that selective flotation rather than bulk is primarily a matter of pH control.

### Calculation of Mill Recovery

If  $h$  = heads assay;  $t$  = tailings assay;  $c$  = concentrates assay;  $r$  = ratio of concentration;  $e$  = per cent. recovery.

$$r = \frac{c - t}{h - t}; e = \frac{100c}{rh}$$

In reference to the use of gravity concentration apparatus ahead of the flotation machines it should be noted that the gravity concentrate is more desirable than the flotation concentrate for smelting.

### FLOTATION MILLING COSTS, 1925

Name	Location	Daily tonnage	Total costs
Utah Copper Co. (2 mills) ..	Garfield, Utah	34,351	\$0 54
Nevada Cons ..	McGill, Nev	8,894	0 511
Ray ..	Hayden, Ariz	8,322	0 63
Chino ..	Hurley, N. M.	8,226	0 761
Miami ..	Miami, Ariz	8,133	0 572
Green Cananea ..	Cananea, Mex.	1,490	0 927
Engels Copper Co ..	Engels, Calif	1,136	0 75
Tenn. Copper & Chem. Co.	Copper Hill, Tenn.	472	0 756
Bunker Hill and Sullivan Co.	Kellogg, Idaho	1,260	0 76

The influence of heavy tonnages in reducing costs is shown very clearly in this table. Several of the companies state that further reductions have been made since the period covered by the reports. Chino's costs were 65.29 cts. in October, 1925. The very low figures reported by the Hecla Mining Company are due partly to the use of jigs and tables for the major part of the concentration, thus decreasing the grinding necessary.

### ALLOCATION OF COSTS

Crushing and grinding .....	\$0.40 to \$0.60
Flotation and dewatering .....	0.10 to 0.15
Reagents .....	0.10 to 0.30
Overhead .....	0.15 to 0.25
Total .....	\$0.75 to \$1.30

The largest plants have costs lower than the above minima.

**Toxic Agents.**—A. M. GAUDIN has the following to say regarding tetravalent and trivalent ions: The extreme toxicity of such reagents as the salts of the tetravalent and trivalent cations has not heretofore been recognized. To emphasize the powerful and generally depressing action of these salts the name toxic agents is proposed, with the understanding that this name is to be extended to the similar but less violent action of salts of divalent and monovalent cations.

The following table shows the sequence in toxicity observed with the nitrates of the various cations, beginning with the most active. The cations in parentheses are those which act as modifiers or activating agents in connection with the mineral under investigation. It is clear that if the cations which act as modifiers are left out, that the order tetravalent—trivalent—divalent—monovalent holds with but few exceptions. In this connection it is of interest to note that trivalent and divalent ions are generally considered good deflocculators and that they most readily change the sign of the charges at the surface of an air bubble or of a solid particle suspended in an aqueous solution containing that ion in solution. The possibility of electrostatic charges playing a preponderant part in connection with the action of these metallic salts deserves a great deal of attention. The alternative possibility which reckons the fact that tetravalent ions hydrolyze more readily than trivalent ions and so on down to monovalent ions which hydrolyze but little, except silver ions, must also be considered.

SEQUENCE OF TOXICITY OBSERVED WITH NITRATES OF  
VARIOUS CATIONS

Pyrite	Galena	Anglesite	Calcite
With xanthate		With sodium oleate	
Ag <sup>+</sup>	Cr <sup>+++</sup>	Zr <sup>++++</sup>	Cr <sup>+++</sup>
Cr <sup>+++</sup>	Th <sup>++++</sup>	Cr <sup>+++</sup>	(Cu <sup>++</sup> )
Hg <sup>++</sup>	Al <sup>+++</sup>	Th <sup>++++</sup>	Al <sup>+++</sup>
Cu <sup>++</sup>	Fe <sup>+++</sup>	Al <sup>+++</sup>	Fe <sup>+++</sup>
Al <sup>+++</sup>	(Hg <sup>++</sup> )	Fe <sup>+++</sup>	Hg <sup>++</sup>
Fe <sup>+++</sup>	(Cu <sup>++</sup> )	H <sup>+</sup>	(Hg <sup>+</sup> )
Pb <sup>++</sup>	(Hg <sup>+</sup> )	Ba <sup>++</sup>	(Ag <sup>+</sup> )
Ni <sup>++</sup>	(Ag <sup>+</sup> )	Cu <sup>++</sup>	Co <sup>++</sup>
Co <sup>++</sup>	Pb <sup>++</sup>	(Ag <sup>+</sup> )	Ni <sup>++</sup>
Ca <sup>++</sup>	Cd <sup>++</sup>	Mg <sup>++</sup>	Ca <sup>++</sup>
	Co <sup>++</sup>	Ni <sup>++</sup>	Ba <sup>++</sup>
	Ni <sup>++</sup>	Sr <sup>++</sup>	Sr <sup>++</sup>
	Ba <sup>++</sup>	Cd <sup>++</sup>	Zn <sup>++</sup>
	Ca <sup>++</sup>		
	Mg <sup>++</sup>		
	H <sup>+</sup>		

## SUMMARIZED COEUR D'ALENE, IDAHO, FLOTATION PRACTICE AND RESULTS

Company	Flotation machines	Chemicals and oils P. P. T.	Metal content in flotation products			
			Feed, per cent.*	Lead concentration, per cent.*	Zinc con- centration, per cent.*	Tailings, per cent.*
Hecla.....	1 8-cell M. S. "Sub-A" 18 in.	Cresylic acid, 0.2; soda ash, 0.1; xanthate, 0.1	Pb, 8.0 • Ag, 4.5 Zn, 0.8	Pb, 50.0 Ag, 28.0 Zn, 4.0	.....	Pb—1.2; Ag, 0.8. Re- treated by flotation re- duced to
	1 8-ft. Callow	Added to first cell of machine. Barrett's No. 4, 0.2	Fe, 8.0		.....	Pb, 0.6 and Ag, 0.3 on.
Hecla.....	3 8-cell 18 in. M. S. "Sub-A." Seven used as roughers and 3 as cleaners. 2.4 hp per cell	Soda ash, 0.05; xanthate, 0.01 and cresylic acid, 0.02 head of flotation machine and to cells. Added to Barrett's No. 4, 0.05 and cresylic acid, 0.04 to ball mill	Pb, 1.2 Ag, 0.8	Pb, 45.0 Ag, 32.0	.....	Pb, 0.13 Ag, 0.09
Callahan.....	1 10-cell 18 in. "Sub- A." Seven cells as roughers and 3 as clean- ers; power required 2.4 hp. per cell	ZnSO <sub>4</sub> , xanthate and Barrett's No. 4 fed to ball mill. Pine oil, 0.05, ahead of flotation machines and to indi- vidual cells	Pb, 6.0 Ag, 4.5 Zn, 1.2 Fe, 17.0	Pb, 53.0 Ag, 38.0 Zn, 8.0	.....	Pb, 0.5 Ag, 0.42
Federal..	Lead section roughers 86 comp. O & D Cleaners: First cleaners, 2 3-comp. O & D; sec- ond and cleaners 2 3 comp. O & D. Zinc section roughers: 2 8 cell 24 in	Galena: ZnSO <sub>4</sub> to ball mill; xanthate, 0.066; ZnSO <sub>4</sub> , 0.72, and wood creosote Cleveland Cliffs No. 1, 0.106. Sphalerite: Xanthate, 0.21; Barrett's No. 4, S, 4.7	Pb, 8.7 Zn, 5.4 Fe, 16.0 Ag, 4.0 Insoluble, 39.7	Pb, 63.1 Zn, 8.3 Fe, 4.0 Ag, 26.5 Insoluble, 2.0	Zn, 48.0 Pb, 4.0 Ag, 4.8	Pb, 0.85 Zn, 0.60 Ag, 0.30





SUMMARIZED COEUR D'ALENE, IDAHO, FLOTATION PRACTICE AND RESULTS. *Continued*

Company	Flotation machines	Chemicals and oils P. P. T.	Metal content in flotation products			
			Feed, per cent.*	Lead concentration, per cent.*	Zinc con- centration, per cent.*	Tailings, per cent.*
<b>Hays</b> .....	4 8-cell 16 in. Fahren- wald machines		•		•	
<b>Constitution</b> ...	<i>Roughers:</i> 3 O & D, 7½- hp each; 1 3-cell K & K requiring 8 hp; 3 Hearing cells requiring cu. ft air at 4 lb; 1 4- cell Fahrenwald requir- ing 6 hp. <i>Cleaners:</i> 4 O & D primary and 2 Hearing cells as final cleaners	10, added to surge tank; xanthate 0.08, added ahead of flota- tion machines	•			
		45-min. treatment in 36 by 8 ft. surge tanks with CuSO <sub>4</sub> , 1.5; Bar- rett's No. 4, 0.10; K- xanthate, 0.10; NaCN, 0.12; lye, 1.5, and pine oil, 0.15. Tail- ings from primary and final cleaners return to surge tanks		<i>Collective Flotation</i> Zn, 43.53 Pb, 18.09 Ag, 11.4 Insoluble, 4.93 Fe, 5.8	..... ... ..	Pb, 1.34 Zn, 1.42 Ag, 0.50
<b>Hercules</b> .....	<i>Lead roughers:</i> 1 12-cell Fahrenwald 18-in. im- pellers requiring 2 hp per cell. <i>Lead clean-</i> <i>ers:</i> Hercules pneuma- tic cells. <i>Zinc rough-</i> <i>ers:</i> 1 10-cell 18 in. M. S. "Sub-A" re- quiring 1.6 hp. exclu- sive of auxiliary air. <i>Zinc cleaners:</i> Hercules pneumatic cells	<i>Galena:</i> Xanthate, cy- anide, zinc sulfate, sodium sulfide, barium sulfide, soda ash, lime, sodium silicate, added in varying amounts and combinations, some to ball mill and some to flotation ma- chine. Oils: Pine oil, Barrett's No. 4, hard wood creosote, and cresylic acid in varying	Custom mill. Some 15 differ- ent ores treated —assay varies widely	Pb, 58 to 60 Zn, 2 to 10	Zn, 47 to 54 Pb, 1 to 4.0	Pb, 0.4 to 1.3 Zn, 0.2 to 0.4

Oregon-Idaho	2 4-cell 15 in. Fahren- wald machines, one cell used as cleaner and seven as roughers	amounts and combina- tions. <i>Sphalerite</i> : Xanthate, soda ash, copper sulfate, sodium sulfide, lime, just pre- ceding circuit. Oils: Pine oil, Barrett's No. 4 P. E. oil in varying amounts and combina- tions	Soda ash, 0.5 added to ball mill; 0.1 xanthate added part at ball mill and part to flotation machines. Cleveland Cliffs No. 1 and No. 5 pine oil	..... Cu, 2.5 Fe, 0.5 Insoluble, 95.0	Copper concen- tration Cu, 40.0 Sb, 0.5 Fe, 1.0 Insoluble, 15.0	..... ..... ..... ..... .....	Cu, 0.6 Mostly as carbonate
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\* Silver in ounces.

According to researches made by the research staff of the United Verde Copper Co. (*Trans. A.I.M.E.*, San Francisco meeting, 1929) lime in a flotation pulp is consumed by adsorption, by reaction with oxidation products on the minerals produced before or during grinding and flotation, by carbon dioxide from the air coming into contact with the pulp and by reaction with constituents of the water used. Grinding an ore in limewater with exclusion of oxygen produced a pulp which gave worse flotation results in flotation of chalcopyrite and sphalerite and rejection of pyrite than one in which plenty of oxygen was present during grinding. The addition of lime to a thick pulp from a grinding mill and conditioning by aerating permitted better subsequent flotation results than adding the same amount of lime to a pulp diluted to flotation density before similar conditioning. The soluble reducing agents produced by action of lime and oxygen, when introduced in controlled quantities similar to those observed in the work recorded above, showed no perceptible effect on the flotation.

## SECTION VII

### CYANIDATION

#### Flow of Sand and Water through Spigots<sup>1</sup>

#### RELATION OF COMPOSITION TO VISCOSITY OF MIXTURES OF SAND AND WATER .

Kilo-grams sand and water	Kilo-grams sand	Kilo-grams and liters water	Liters sand	Liters sand and water	Per cent. sand by volume	Per cent. sand by weight	Viscosity of mixture
9.20	0.00	9.20	0.000	9.20	0.00	0.00	1.00
9.30	0.45	8.85	0.165	9.02	1.83	4.84	1.02
9.35	1.10	8.25	0.405	8.66	4.68	11.8	1.06
9.35	1.40	7.95	0.515	8.47	6.08	15.0	1.09
9.40	1.90	7.50	0.699	8.20	8.53	20.2	1.12
9.40	1.95	7.45	0.717	8.17	8.78	20.8	1.13
9.55	2.20	7.35	0.809	8.16	9.92	22.0	1.13
9.20	2.25	6.95	0.827	7.78	10.6	24.4	1.18
9.05	2.50	6.55	0.920	7.47	12.3	27.6	1.23

A concrete example, illustrating the use of the data given above, may prove of interest. It is desired to discharge from the pocket of a classifier 40 tons of sand per 24 hours together with water in the ratio of 1 part of sand to 3 parts of water by weight. The head of water above the spigot is 3 ft. The form of the spigot is that of a short tube with a conical mouth on the influx end. The mean specific gravity of the sand is 2.81. What must be the diameter of the spigot opening? For the sake of convenience, metric units are used in making the calculation. The area of the spigot opening may be obtained from the formula:

$$a = \frac{fq}{c\sqrt{2gh}}$$

Taking up the terms on the right hand of the equation in order,  $f$  the viscosity, may be estimated as follows: The weight ratio of water to sand in the mixture to be discharged is 3 to 1. Considering 100 grams of the mixture, the weight of water is 75 grams; its volume is 75 cc. The volume of the sand is 25 grams  $\div$  2.81 (the density of the sand) = 8.9 cc. The total volume of 100 grams of the mixture is 75 + 8.9 = 83.9 cc. Hence the percentage of sand by volume in the mixture is 8.9  $\div$  83.9 = 10.6. From the lower curve of Fig. 1, the viscosity of a mixture containing 10.6 per cent. of sand by volume is 1.17. Therefore,  $f = 1.17$ . The quantity of sand discharged per 24 hours is 40 tons. One

<sup>1</sup> RICHARDS and DUDLEY, *Trans. A. I. M. E.*, January, 1915.

ton per 24 hours is  $0.631 \frac{1}{2}$  kg. per minute. Forty tons per 24 hours is  $40 \times 0.631 = 25.2$  kg. per minute. The volume of sand per minute is  $25.2 \div 2.81$  (the density) = 8.98 liters. The quantity of water per minute is three times that of the sand  $25.2 \times 3 = 75.6$  kg. = 75.6 liters. The total volume of sand and water per minute is  $8.98$  (sand) +  $76.5$  (water) =  $85.5 \div 60 = 1.43$  liters = 1430 cc.

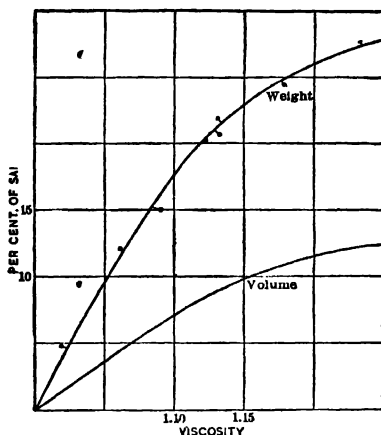


FIG. 1.—Graphic representation of results shown in table on p. 519.

Since the spigot is to consist of a short tube with a conical mouth on the influx end, the coefficient of discharge,  $c$ , may be assumed as 0.88. Substituting these values in the above equation gives for the area of the spigot opening:

$$a = \frac{1.17 \times 1430}{0.88 \sqrt{2 \times 980 \times 914}} = 1.42 \text{ sq. cm.}$$

The diameter may be obtained from the relation:

$$\sqrt{\frac{a}{n}} d = 1.35 \text{ cm.} = 0.53 \text{ in.}$$

### Pulp Constants

In an article by G. H. CLEVINGER, H. W. YOUNG and T. N. TURNER (*Eng. and Min. Journ.*, Dec. 19, 1914) it was shown that the ordinary calculations for contents of tanks, weights of tailings, etc.; based on the assumption that the specific gravity of the solution was 1, were incorrect by large amounts. CLEVINGER worked out a set of complete tables covering these constants, of which only the basic formulas are here given.

Let  $a$  = Specific gravity of wet pulp.

$S$  = Specific gravity of dry slime.

- $V$  = Total volume of wet pulp.  
 $m$  = Total weight of dry slime in wet pulp.  
 $c$  = Volume of solution in wet pulp.  
 $d$  = Specific gravity of solution.  
 $P$  = Percentage of dry slime in wet pulp.

$$a = \frac{m + cd}{V} \quad S = \frac{m}{(V - c)}$$

Solving for  $c$ , equating values, simplifying and solving for  $m$ :

$$m = \frac{SV(a - d)}{(S - d)}$$

$P$  is obtained by multiplying the above value of  $m$  by 100 and dividing by weight of the wet pulp,  $Va$ :

$$P = \frac{100S(a - d)}{a(S - d)}$$

The error introduced by assuming  $d = 1$  is not a negligible one.

#### SPECIFIC GRAVITY OF WORKING CYANIDE SOLUTIONS

Solution	Specific gravity	
Fresh solution.....		1.00170
Butters plant, Virginia City, Nev...	Heads	1.00281
Butters plant, Virginia City, Nev...	Tails	1.00279
Belmont plant, Tonopah, Nev.....	Heads	1.00881
Belmont plant, Tonopah, Nev...	Tails	1.00873
Montana-Tonopah, Tonopah, Nev..	Heads	1.00314
Empire, Grass Valley, Calif. ....	Heads	1.00142
Portland, Colorado Springs, Colo..	Heads	1.01000
South Africa, average.....		1.00210
Pittsburgh-Silver Peak, Blair, Nev..	Heads	1.00309

#### SLIME COAGULANTS<sup>1</sup>

Substances	Quantities required by weight, to produce equal effects
Aluminum sulphate.....	100
Alum (potassium aluminum) ..	143
Ferric sulphate.....	223
Alum (ammonium).....	252
Alum (ammonium-chromium).....	295
Lime.....	654
Magnesia.....	748
Alum (potassium-chromium) ..	958
Calcium chloride.....	1,095
Calcium carbonate.....	1,215
Calcium sulphate.....	2,870
Magnesium sulphate.....	3,460
Sodium chloride.....	45,900
Sodium sulphate.....	61,700

<sup>1</sup> MEGRAW, "Practical Data for the Cyanide Plant," adapted from JULIAN and SMART.

# 522 METALLURGISTS AND CHEMISTS' HANDBOOK

## NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF CYLINDRICAL TANKS<sup>1</sup>

Diam., inches	Diameter, feet										
	10	11	12	13	14	15	16	17	18	19	20
0	78.54	95.03	113.1	132.7	153.9	176.7	201.1	227.0	254.5	283.5	314.2
½	79.19	95.75	113.9	133.5	154.8	177.7	202.1	228.1	255.6	284.7	315.5
1	79.85	96.48	114.7	134.4	155.8	178.7	203.2	229.2	256.8	286.0	316.8
1½	80.51	97.20	115.5	135.3	156.7	179.7	204.2	230.3	258.0	287.2	318.1
2	81.18	97.93	116.3	136.2	157.6	180.7	205.3	231.5	259.2	288.5	319.4
2½	81.85	98.66	117.1	137.0	158.5	181.7	206.3	232.6	260.4	289.7	320.7
3	82.52	99.40	117.9	137.9	159.5	182.7	207.4	233.7	261.6	291.0	322.1
3½	83.19	100.1	118.7	138.7	160.4	183.7	208.4	234.8	262.8	292.3	323.4
4	83.86	100.9	119.5	139.6	161.4	184.7	209.5	236.0	264.0	293.6	324.7
4½	84.54	101.6	120.3	140.5	162.3	185.7	210.6	237.1	265.2	294.8	326.0
5	85.22	102.4	121.1	141.4	163.2	186.7	211.7	238.2	266.4	296.1	327.4
5½	85.90	103.1	121.9	142.2	164.1	187.7	212.7	239.3	267.6	297.3	328.7
6	86.59	103.9	122.7	143.1	165.1	188.7	213.8	240.5	268.8	298.6	330.1
6½	87.28	104.6	123.5	144.0	166.0	189.7	214.9	241.6	270.0	299.9	331.4
7	87.97	105.4	124.4	144.9	167.0	190.7	216.0	242.8	271.2	301.2	332.8
7½	88.66	106.1	125.2	145.8	167.9	191.7	217.1	243.9	272.4	302.5	334.1
8	89.36	106.9	126.0	146.7	168.9	192.8	218.2	245.1	273.7	303.8	335.5
8½	90.06	107.6	126.8	147.6	169.9	193.8	219.3	246.2	274.9	305.1	336.8
9	90.76	108.4	127.7	148.5	170.9	194.8	220.4	247.4	276.1	306.4	338.2
9½	91.47	109.2	128.5	149.4	171.8	195.8	221.5	248.6	277.3	307.6	339.5
10	92.18	110.0	129.4	150.3	172.8	196.9	222.6	249.8	278.6	308.9	340.9
10½	92.89	110.7	130.2	151.2	173.8	197.9	223.7	250.9	279.8	310.2	342.2
11	93.60	111.5	131.0	152.1	174.8	199.0	224.8	252.1	281.0	311.5	343.6
11½	94.31	112.3	131.8	153.0	175.7	200.0	225.9	253.3	282.2	312.8	345.0

## NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF CYLINDRICAL TANKS.<sup>1</sup> *Continued*

Diam., inches	Diameter, feet										
	21	22	23	24	25	26	27	28	29	30	31
0	346.4	380.1	415.5	452.4	490.9	530.9	572.6	615.8	660.5	706.9	754.8
½	347.7	381.5	417.0	453.9	492.5	532.6	574.3	617.6	662.4	708.8	756.8
1	349.1	383.0	418.5	455.5	494.2	534.3	576.1	619.4	664.3	710.8	758.8
1½	350.5	384.4	420.0	457.1	495.8	536.0	577.8	621.2	666.2	712.7	760.8
2	351.9	385.9	421.5	458.7	497.4	537.8	579.6	623.1	668.1	714.7	762.9
2½	353.3	387.3	423.0	460.3	499.0	539.5	581.4	624.9	670.0	716.7	764.9
3	354.7	388.8	424.6	461.9	500.7	541.2	583.2	626.8	672.0	718.7	767.0
3½	356.0	390.2	426.1	463.4	502.4	542.9	585.0	628.6	673.9	720.7	769.0
4	357.4	391.7	427.6	465.0	504.1	544.6	586.8	630.5	675.8	722.7	771.1
4½	358.8	393.2	429.1	466.6	505.7	546.3	588.6	632.3	677.7	724.6	773.1
5	360.2	394.7	430.7	468.2	507.4	548.1	590.4	634.2	679.6	726.6	775.2
5½	361.6	396.1	432.2	469.8	509.0	549.8	592.2	636.0	681.5	728.6	777.2
6	363.1	397.6	433.7	471.4	510.7	551.5	594.0	637.9	683.5	730.6	779.3
6½	364.5	399.1	435.2	473.0	512.3	553.2	595.8	639.8	685.4	732.6	781.3
7	365.9	400.6	436.8	474.6	514.0	555.0	597.6	641.7	687.4	734.6	783.4
7½	367.3	402.0	438.3	476.2	515.7	556.7	599.4	643.5	689.3	736.6	785.5
8	368.7	403.5	439.9	477.9	517.4	558.5	601.2	645.4	691.2	738.6	787.6
8½	370.1	405.0	441.4	479.5	519.1	560.2	603.0	647.3	693.1	740.6	789.6
9	371.5	406.5	443.0	481.1	520.8	562.0	604.8	649.2	695.1	742.0	791.7
9½	372.9	408.0	444.5	482.7	522.4	563.7	606.6	651.0	697.0	744.6	793.8
10	374.4	409.5	446.1	484.4	524.1	565.6	608.4	652.9	699.0	746.7	795.9
10½	375.8	411.0	447.7	486.0	525.8	567.2	610.2	654.8	700.9	748.7	798.0
11	377.3	412.5	449.3	487.6	527.5	569.0	612.1	656.7	702.9	750.7	800.1
11½	378.7	414.0	450.8	489.2	529.2	570.8	613.9	658.6	704.9	752.7	802.1



NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF  
CYLINDRICAL TANKS.<sup>1</sup> *Continued*

Diameter, inches	Diameter, feet										
	32	33	34	35	36	37	38	39	40	41	2
0	804.2	855.3	907.9	962.1	1018	1075	1134	1195	1257	1320	1385
½	800.3	857.4	910.1	964.4	1020	1077	1136	1197	1259	1323	1388
1	808.4	859.6	912.4	966.7	1023	1080	1139	1200	1262	1326	1391
1½	810.5	861.8	914.6	969.0	1025	1082	1141	1202	1264	1328	1393
2	812.6	864.0	916.8	971.3	1027	1085	1144	1205	1267	1331	1396
2½	814.7	866.1	919.0	973.6	1029	1087	1146	1207	1269	1333	1399
3	816.9	868.3	921.3	975.9	1032	1090	1149	1210	1272	1336	1402
3½	819.0	870.5	923.5	978.2	1034	1092	1151	1212	1275	1339	1405
4	821.1	872.7	925.8	980.5	1037	1095	1154	1215	1278	1342	1408
4½	823.2	874.8	928.0	982.8	1039	1097	1156	1217	1280	1344	1410
5	825.3	877.0	930.3	985.2	1042	1100	1159	1220	1283	1347	1413
5½	827.4	879.2	932.5	987.5	1044	1102	1161	1222	1285	1350	1416
6	829.6	881.4	934.8	989.8	1046	1104	1164	1225	1288	1353	1419
6½	831.7	883.6	937.0	992.1	1048	1106	1166	1228	1291	1355	1421
7	833.8	885.8	939.3	994.5	1051	1109	1169	1231	1294	1358	1424
7½	835.9	888.0	941.6	996.8	1053	1111	1171	1233	1296	1361	1427
8	838.1	890.2	943.9	999.1	1056	1114	1174	1236	1299	1364	1430
8½	840.2	892.4	946.1	1001	1058	1116	1176	1238	1301	1366	1432
9	842.4	894.6	948.4	1004	1061	1119	1179	1241	1304	1369	1435
9½	844.5	896.8	950.1	1006	1063	1121	1181	1243	1307	1371	1438
10	846.7	899.0	953.0	1008	1066	1124	1184	1246	1310	1374	1441
10½	848.8	901.2	955.2	1010	1068	1126	1186	1248	1312	1377	1444
11	851.0	903.5	957.5	1013	1070	1129	1189	1251	1315	1380	1447
11½	853.1	905.7	959.8	1015	1072	1131	1192	1254	1317	1382	1450

NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF  
CYLINDRICAL TANKS.<sup>1</sup> *Continued*

Diameter, inches	Diameter, feet											
	43	44	45	46	47	48	49	50	51	52	53	54
0	1452	1521	1590	1662	1735	1810	1886	1963	2043	2124	2206	2290
½	1455	1523	1593	1665	1738	1813	1889	1966	2046	2127	2209	2293
1	1458	1526	1596	1668	1741	1816	1892	1970	2050	2131	2213	2297
1½	1460	1529	1599	1671	1744	1819	1895	1973	2053	2134	2216	2300
2	1463	1532	1602	1674	1747	1822	1899	1977	2056	2137	2220	2304
2½	1466	1535	1605	1677	1750	1825	1902	1980	2059	2140	2223	2307
3	1469	1538	1608	1680	1753	1828	1905	1983	2063	2144	2227	2311
3½	1472	1541	1611	1683	1756	1831	1908	1986	2066	2147	2230	2315
4	1475	1544	1614	1686	1760	1835	1911	1990	2070	2151	2234	2319
4½	1477	1546	1617	1689	1763	1838	1914	1993	2073	2154	2237	2322
5	1480	1549	1620	1692	1766	1841	1918	1996	2076	2158	2241	2326
5½	1483	1552	1623	1695	1769	1844	1921	1999	2079	2161	2244	2329
6	1486	1555	1626	1698	1772	1847	1924	2003	2083	2165	2248	2333
6½	1489	1558	1629	1701	1775	1850	1927	2006	2086	2168	2251	2336
7	1492	1561	1632	1704	1778	1854	1931	2010	2090	2172	2255	2340
7½	1495	1564	1635	1707	1781	1857	1934	2013	2093	2175	2258	2343
8	1498	1567	1638	1710	1785	1860	1937	2016	2097	2179	2262	2347
8½	1500	1570	1641	1713	1788	1863	1940	2019	2100	2182	2265	2351
9	1503	1573	1644	1717	1791	1867	1944	2023	2103	2185	2269	2354
9½	1506	1576	1647	1720	1794	1870	1947	2026	2106	2188	2273	2357
10	1509	1579	1650	1723	1797	1873	1950	2029	2110	2192	2276	2361
10½	1512	1582	1653	1726	1800	1876	1953	2032	2113	2195	2279	2365
11	1515	1585	1656	1729	1803	1879	1957	2036	2117	2199	2283	2369
11½	1518	1587	1659	1732	1806	1882	1960	2039	2120	2202	2286	2372

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## NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF CYLINDRICAL TANKS.<sup>1</sup> *Continued*

Diameter, inches	Diameter, feet										
	55	56	57	58	59	60	61	62	63	64	65
0	2376	2463	2552	2642	2734	2827	2922	3019	3117	3217	3318
1/4	2379	2466	2555	2646	2738	2831	2926	3023	3121	3221	3322
1	2383	2470	2559	2650	2742	2835	2930	3027	3125	3225	3327
1 1/4	2386	2474	2563	2653	2745	2839	2934	3031	3129	3229	3331
2	2390	2478	2567	2657	2749	2843	2938	3035	3134	3234	3335
2 1/4	2393	2481	2570	2661	2753	2847	2942	3039	3138	3238	3339
3	2397	2485	2574	2665	2757	2851	2946	3043	3142	3242	3344
3 1/4	2401	2488	2578	2669	2761	2855	2950	3047	3146	3246	3348
4	2405	2492	2582	2673	2765	2859	2954	3052	3150	3251	3352
4 1/4	2408	2496	2585	2676	2769	2863	2958	3056	3154	3255	3356
5	2412	2500	2589	2680	2773	2867	2963	3060	3159	3259	3361
5 1/4	2415	2503	2593	2684	2777	2871	2967	3064	3163	3263	3365
6	2419	2507	2597	2688	2781	2875	2971	3068	3167	3267	3370
6 1/4	2422	2511	2600	2691	2784	2879	2975	3072	3171	3271	3374
7	2426	2515	2604	2695	2788	2883	2979	3076	3175	3276	3378
7 1/4	2430	2518	2608	2699	2792	2887	2983	3080	3179	3280	3382
8	2434	2522	2612	2703	2796	2891	2987	3084	3184	3284	3387
8 1/4	2437	2525	2615	2707	2800	2895	2991	3088	3188	3288	3391
9	2441	2529	2619	2711	2804	2899	2995	3093	3192	3293	3395
9 1/4	2444	2533	2623	2715	2808	2903	2999	3097	3196	3297	3399
10	2448	2537	2627	2719	2812	2907	3003	3101	3200	3301	3404
10 1/4	2452	2540	2630	2722	2816	2910	3007	3105	3204	3305	3408
11	2456	2544	2634	2726	2820	2914	3011	3109	3209	3310	3413
11 1/4	2459	2548	2638	2730	2823	2918	3015	3113	3213	3314	3417

## NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF CYLINDRICAL TANKS.<sup>1</sup> *Continued*

Diameter, inches	Diameter, feet										
	66	67	68	69	70	71	72	73	74	75	76
0	3421	3526	3632	3739	3848	3959	4072	4185	4301	4418	4536
1/4	3425	3530	3636	3743	3853	3963	4076	4190	4306	4423	4541
1	3430	3534	3641	3748	3858	3968	4081	4195	4311	4428	4546
1 1/4	3434	3538	3645	3752	3862	3973	4085	4200	4315	4433	4551
2	3438	3543	3650	3757	3867	3978	4090	4205	4320	4438	4556
2 1/4	3442	3547	3654	3761	3871	3982	4095	4209	4325	4442	4561
3	3447	3552	3658	3766	3876	3987	4100	4214	4330	4447	4566
3 1/4	3451	3556	3662	3770	3880	3991	4104	4219	4335	4452	4571
4	3456	3561	3667	3775	3885	3996	4109	4224	4340	4457	4576
4 1/4	3460	3565	3671	3780	3889	4001	4114	4228	4344	4462	4581
5	3465	3570	3676	3785	3894	4006	4119	4233	4349	4467	4586
5 1/4	3469	3574	3680	3789	3899	4010	4123	4238	4354	4472	4591
6	3473	3578	3685	3794	3904	4015	4128	4243	4359	4477	4596
6 1/4	3477	3582	3689	3798	3908	4020	4133	4248	4364	4482	4601
7	3482	3587	3694	3803	3913	4025	4138	4253	4369	4487	4606
7 1/4	3486	3591	3698	3807	3917	4029	4142	4257	4374	4492	4611
8	3491	3596	3703	3812	3922	4034	4147	4262	4379	4497	4616
8 1/4	3495	3600	3707	3816	3926	4038	4152	4267	4383	4502	4621
9	3499	3605	3712	3821	3931	4043	4157	4272	4388	4507	4626
9 1/4	3503	3609	3716	3825	3936	4048	4161	4276	4393	4512	4631
10	3508	3614	3721	3830	3941	4053	4166	4281	4398	4517	4636
10 1/4	3512	3618	3725	3834	3945	4057	4171	4286	4403	4522	4641
11	3517	3623	3730	3839	3950	4062	4176	4291	4408	4527	4647
11 1/4	3521	3627	3734	3843	3954	4067	4180	4296	4413	4531	4652

NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF  
CYLINDRICAL TANKS.<sup>1</sup> *Continued*

Diameter, inches	Diameter, feet										
	77	78	79	80	81	82	83	84	85	86	87
0	4657	4778	4902	5027	5153	5281	5411	5542	5675	5809	5945
½	4662	4783	4907	5032	5158	5286	5416	5547	5680	5814	5950
1	4667	4789	4912	5037	5164	5292	5421	5553	5686	5820	5956
1½	4672	4794	4917	5042	5169	5297	5426	5558	5691	5825	5961
2	4677	4799	4922	5048	5174	5303	5432	5564	5697	5831	5967
2½	4682	4804	4927	5053	5179	5308	5437	5569	5702	5837	5973
3	4687	4809	4933	5058	5185	5313	5443	5575	5708	5843	5979
3½	4692	4814	4938	5063	5190	5318	5448	5580	5713	5848	4984
4	4697	4819	4943	5069	5195	5324	5454	5586	5719	5854	5990
4½	4702	4824	4948	5074	5200	5329	5459	5591	5724	5859	5996
5	4707	4830	4954	5079	5206	5335	5465	5597	5730	5865	6002
5½	4712	4835	4959	5084	5211	5340	5470	5602	5735	5871	6007
6	4717	4840	4964	5090	5217	5346	5476	5608	5741	5877	6013
6½	4722	4845	4969	5095	5222	5351	5481	5613	5747	5882	6019
7	4727	4850	4974	5100	5227	5356	5487	5619	5753	5888	6025
7½	4732	4855	4979	5105	5232	5361	5492	5624	5758	5893	6030
8	4738	4860	4985	5111	5238	5367	5498	5630	5764	5899	6036
8½	4743	4865	4990	5116	5243	5372	5503	5635	5769	5905	6042
9	4748	4871	4995	5121	5249	5378	5509	5641	5775	5911	6048
9½	4753	4876	5000	5126	5254	5383	5514	5646	5780	5916	6053
10	4758	4881	5006	5132	5260	5389	5520	5652	5786	5922	6059
10½	4763	4886	5011	5137	5265	5394	5525	5657	5792	5927	6065
11	4768	4891	5016	5142	5270	5400	5531	5663	5798	5933	6071
11½	4773	4896	5021	5147	5275	5405	5536	5669	5803	5939	6076

NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF  
CYLINDRICAL TANKS.<sup>1</sup> *Continued*

Diameter, inches	Diameter, feet											
	88	89	90	91	92	93	94	95	96	97	98	99
0	6082	6221	6362	6504	6648	6793	6940	7088	7238	7390	7543	7698
½	6088	6227	6368	6510	6654	6799	6946	7094	7244	7396	7549	7704
1	6094	6233	6374	6516	6660	6805	6952	7101	7251	7403	7556	7711
1½	6099	6238	6379	6522	6666	6811	6958	7107	7257	7409	7562	7717
2	6105	6244	6385	6528	6672	6817	6964	7113	7263	7415	7569	7724
2½	6111	6250	6391	6534	6678	6823	6970	7119	7269	7421	7575	7730
3	6117	6256	6397	6540	6684	6829	6977	7126	7276	7428	7581	7737
3½	6122	6262	6403	6546	6690	6835	6983	7132	7282	7434	7587	7743
4	6128	6268	6409	6552	6696	6842	6989	7138	7289	7441	7594	7750
4½	6134	6274	6415	6558	6702	6848	6995	7144	7295	7447	7600	7756
5	6140	6280	6421	6564	6708	6854	7001	7151	7301	7453	7607	7763
5½	6145	6285	6427	6570	6714	6860	7007	7157	7307	7459	7613	7769
6	6151	6291	6433	6576	6720	6866	7014	7163	7314	7466	7620	7776
6½	6157	6297	6438	6582	6726	6872	7020	7169	7320	7472	7626	7782
7	6163	6303	6444	6588	6732	6878	7026	7176	7326	7479	7633	7789
7½	6169	6309	6450	6594	6738	6884	7032	7182	7332	7485	7639	7795
8	6175	6315	6456	6600	6744	6891	7039	7188	7339	7492	7646	7802
8½	6180	6320	6462	6606	6750	6897	7045	7194	7345	7498	7652	7808
9	6186	6326	6468	6612	6756	6903	7051	7201	7352	7505	7659	7815
9½	6192	6332	6474	6618	6762	6909	7057	7207	7358	7511	7665	7821
10	6198	6338	6480	6624	6769	6915	7063	7213	7364	7517	7672	7828
10½	6203	6344	6486	6630	6775	6921	7069	7219	7370	7523	7678	7834
11	6209	6350	6492	6636	6781	6927	7076	7226	7377	7530	7685	7841
11½	6215	6356	6498	6642	6787	6933	7082	7232	7383	7536	7691	7847

<sup>1</sup> G. H. CLEVENGER, et al., "Pulp Constants," *Eng. and Min. Jour.*, Dec. 19, 1914.

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OPERATING DATA ON DORR THICKENERS<sup>1</sup>

Mill	Sq. ft. settling area per ton of solids thickened per 24 hr.	Sq. ft. settling area per gallon overflowed per minute	Remarks
San Rafael, Mexico	4 5	..	Tube-mill product, 75 per cent - 200 mesh, discharge 45 5 per cent. solids.
Liberty Bell, Colorado.	15.0	12.6	Tube-mill product, much light argillaceous slime. Discharge 33 per cent. solids: +100, 17 per cent.; +200, 13 per cent.; - 200, 70 per cent. Feed 9:1. Solution fed at capacity; solids not. Large area per gallon overflowed per minute due to density of underflow and nature of the slime.
Mogul, South Dakota.	3.92	....	Tube-mill product, ore siliceous +60, 0.6 per cent.; +100, 7 8 per cent.; +200, 26 per cent; - 200, 65 6 per cent. Discharge 56 to 59 per cent solids. Continuous decantation
Batopilas, Mexico	0.6 to 0.9	..	40-mesh product; 90 per cent passing 100 mesh.
Zambona, Mexico	3 1	....	Tube-mill product. Discharge 40 per cent solids.
Dominton, Ontario	5 4	.	Tube-mill product, 88 per cent - 200 mesh, ore diabase. Discharge 40 per cent. solids Feed 6:1.
Porcupine-Crown, Ontario.	4.25	.	Tube-mill product, 75 per cent - 200 mesh. Discharge 65 per cent. solids. Quartz ore. Continuous decantation. With 5 1 sq ft. settling area per ton settles to 71 to 73 per cent solids.
El Palmarito, Mexico	4.5	..	Tube-mill product: pure quartzite, 97 per cent. - 200 mesh Feed 7:1. Discharge 65 to 70 per cent. solids. Continuous decantation.
Amparo, Jalisco, Mex.	4 9	1 4	Tube-mill product, siliceous 93.5 per cent. - 200 mesh Feed 24.5:1. Discharge 23 5 per cent. solids; used to feed vanners.
Veta, Colorado, Parral, Mex.	5 0	3 1/2	Tube-mill product, rather argillaceous: 71 per cent. - 200 mesh. Feed 11:1. Discharge 33 per cent solids for agitator Have settled to 65 per cent solids.
Smuggler-Union, Telluride, Colo	.....	....	Very clayey slime with classified sand. Screen test: +40, 1.48 per cent.; +60, 7.27 per cent.

<sup>1</sup> *Metallurgical and Chemical Engineering*, February, 1915.

a. Not up to capacity of overflow.

OPERATING DATA ON DORR THICKENERS. *Continued*

Mill	Sq. ft. settling area per ton of solids thickened per 24 hr.	Sq. ft. settling area per gallon overflowed per minute	Remarks
Smuggler-Union, Telluride, Colo.	.....	.....	+100, 14.81 per cent.; +200, 11.63 per cent.; -200, 65.81 per cent.
	30.0	26 0	Settling from cold water, slightly alkaline. Feed 8:1. Discharge 50 per cent. solids, 1.429 sp. gr.
	10 0		Settling from cyanide solution. Feed, 2 5:1. Discharge 40 per cent. solids, 1.316 sp. gr.
A large copper company, Arizona	11.6	8.11	Considerable argillaceous slime. Feed 10.4 per cent. solids. Discharge 25.3 per cent. solids.
Pennsylvania Steel, Lebanon, Pa	14.2	2.48	Thickening ahead of vanner concentration. Feed 2.8 per cent. solids. Discharge 10.6 per cent. solids. Overflow 0.4 per cent. solids, extremely fine, which does not interfere with using water again.
Nevada Consolidated, Ely, Nev		1 25	"Each 17-ft. thickener supplies wash water for 20 Wilfley tables and occasionally for wash on vanners. One thickener has a greater capacity than twelve 8-ft. cones." Area of 17-ft. tank is 226 sq. ft.; of the twelve 8-ft. cones, 525 sq. ft.
Broken Hill, Proprietary, Australia.		1 10	Dewatering slime from lead-zinc concentration mill. Feed 100:1. Discharge 55 per cent. solids.
Anaconda Copper, Mont.		5 95	Dewatering slime from concentrator. Forty 4-deck thickeners, each 28 ft. in diameter by 3 ft. 3 in. deep, handle about 26,000,000 gal of pulp per day which contains approximately 2 per cent. solids. A clear overflow obtained, the underflow containing about 15 per cent. solids, which is fed to buddles.

The data given here show that when pulp is carried in cyanide solution a provision of 5 to 6 sq. ft. per ton for a siliceous tube mill product is ample and from 7 to 15 sq. ft. for a clayey material or classified slime product. When very dilute products are handled the area required is determined usually by the gallons per minute to be overflowed.

POWER DETAILS FOR PACHUCA TANKS<sup>1</sup>

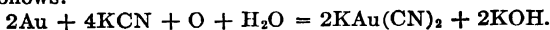
Tank, diam. × ht., feet	Ore	Charge tons	Free air, cu. ft.	Pres- sure, lb. per sq. in.	Horse- power	Pulp
7.5×37	Slime.....	15	5	22	0.5	Thin.
7.5×37	Concentrate...	40	17	26	2.0	Thin.
10×40	Slime.....	35	9	22	0.75	Thin.
13×55	Slime.....	110	16	33	1.75	Thin.
10×40	Fine sand.....	50	25	22	2.25	Thin.
7.5×37	Battery pulp.....	.....	14	22	1.4	Thickened.
10×40	Battery pulp.....	.....	22	23	2.3	Thickened.
13×55	Battery pulp.....	.....	38	35	4.0	Thickened.

<sup>1</sup> *Eng. and Min. Journ.*, Vol. LXXXVI, 1908, p. 901.

This estimation of horsepower required conforms to the popular ideas on that point. On the basis of some careful tests which have been made, however, it is probable that actual power consumption is considerably higher.

### Principles of Cyanidation

The cyanide process is based upon the solubility of gold and silver, and of some of the compounds of both metals, in an alkaline cyanide. The chemical theory is expressed in Elsner's equation, which was first brought forward by him to show the action of oxygen in the dissolution of precious metals. It is as follows:



The usual cyanide salt was formerly potassium cyanide, but for reasons of economy, the sodium salt is principally used at the present time. The commercial product contains about 125 to 128 per cent. of the required compound in terms of KCN.

The essential difference between gold and silver cyanidation is that the gold is almost universally present as a free metal, and the cyanide dissolves the gold only. On the contrary, silver is seldom present in the free state, and usually occurs as a sulphide, chloride, or bromide. The sulphide is the most rebellious of all the compounds, except those which contain highly complex mixtures of antimony, arsenic, cobalt and nickel, but all of these can be treated. Silver sulphide often goes into solution as a sulphide, and it requires some manipulation to separate the silver as a metal.

The consumption of cyanide varies from as low as 0.1 lb. per ton of ore treated, in the case of fine free gold disseminated in pure quartz with no cyanide, to as much as 5 or 6 lb. per ton in the case of semi-rebellious silver ores. Of course the limit of cyanide consumption depends entirely upon the richness of the ore to be treated. A rich ore will stand a higher consumption than a poor ore. Under ordinary commercial conditions, however, about 5 or 6 lb. per ton would be the limit on ore no matter how high its grade, since the consumption of much more cyanide than this would throw the cost up into competition with the smelting processes, under which circumstances smelting would be preferable to cyanide treatment.

### Good Uses for Old Belting

By L. D. ANDERSON<sup>1</sup>

The "bone yard" or scrap heap of every mill usually includes a large amount of worn-out belting. This material can be used to good purpose in several ways.

It makes an excellent cover for wooden stair treads. These treads wear out fast when used constantly by men in hob-nailed shoes. Metal treads last longer, but soon become worn smooth, when they constitute an actual menace. But wooden treads with pieces of old belting nailed to them have their life prolonged to a surprising degree and at the same time afford a secure footing. Canvas belting is better than rubber, as it does not become slippery when wet.

Again, there are many places in wet concentrating mills where the laying of canvas belting on the floor would do much to prevent accidents. Wet slimy material, despite the most careful work frequently slops over and runs on the floor. It is easy for a man in a hurry to slip up in a puddle of slime and perhaps fall into a moving machine. The rough surface of old canvas belt would do much to prevent this.

### Capacities of Cylindrical Tanks

T. F. CORCORAN furnishes the table on pp. 530-531 for the capacities of cylindrical tanks in a horizontal position. The depth is expressed directly in inches and the coefficient  $C$  represents the volume in cubic feet of a tank 1 ft. long. The volume of the end portions is of course independent of the length of the tank. All that is required with this table is to multiply the coefficient  $C$  at any given depth in inches by the length of the tank and add or subtract the volume of the end portions corresponding to the given depth.

This table has been made up to only 50 per cent. of the tank depth because it has been used mainly for making up calibration tables for each individual tank, this being desirable where the tanks are measured frequently. However, if a tank is more than half full it is a simple matter to subtract the volume of the empty space from the total volume of the tank.

<sup>1</sup> Superintendent, United States Smelting Co., Midvale, Utah.

In.	3 ft. diam.		4 ft. diam.		4½ ft. diam.		5 ft. diam.		6 ft. diam.		7 ft. diam.		8 ft. diam.		10 ft. diam.		In.
	C	Vh	C	Vh	C	Vh	C	Vh	C	Vh	C	Vh	C	Vh	C	Vh	
1	.056	..	.064	..	.070	..	.074	..	.079	..	.086	..	.090	..	.101	..	1
2	.137	..	.181	..	.190	..	.198	..	.223	..	.241	..	.258	..	.286	..	2
3	.280	..	.331	..	.352	..	.367	..	.408	..	.441	..	.461	..	.523	..	3
4	.428	..	.498	..	.531	..	.566	..	.625	..	.677	..	.725	..	.791	..	4
5	.595	..	.693	..	.744	..	.777	..	.852	..	.932	..	.996	..	1.123	..	5
6	.777	..	.907	..	.965	..	1.022	..	1.119	..	1.209	..	1.324	..	1.468	..	6
7	.963	..	1.136	..	1.215	..	1.286	..	1.407	..	1.523	..	1.645	..	1.830	..	7
8	1.168	..	1.381	..	1.457	..	1.551	..	1.715	..	1.858	..	1.989	..	2.265	..	8
9	1.382	..	1.637	..	1.747	..	1.847	..	2.040	..	2.212	..	2.388	..	2.676	..	9
10	1.604	..	1.893	..	2.025	..	2.137	..	2.381	..	2.584	..	2.771	..	3.108	..	10
11	1.833	..	2.170	..	2.330	..	2.461	..	2.737	..	2.973	..	3.211	..	3.616	..	11
12	2.058	..	2.458	..	2.628	..	2.796	..	3.106	..	3.377	..	3.626	..	4.088	..	12
13	2.300	..	2.752	..	2.952	..	3.141	..	3.488	..	3.771	..	4.000	..	4.576	..	13
14	2.544	..	3.054	..	3.268	..	3.475	..	3.895	..	4.228	..	4.546	..	5.145	..	14
15	2.791	..	3.362	..	3.609	..	3.839	..	4.258	..	4.673	..	5.004	..	5.666	..	15
16	3.031	..	3.661	..	3.939	..	4.210	..	4.672	..	5.139	..	5.523	..	6.203	..	16
17	3.282	..	3.981	..	4.293	..	4.568	..	5.095	..	5.558	..	6.006	..	6.823	..	17
18	3.534	..	4.304	..	4.634	..	4.954	..	5.528	..	6.035	..	6.549	..	7.388	..	18
19	..	..	4.632	..	5.000	..	5.347	..	5.968	..	6.522	..	7.055	..	8.029	..	19
20	..	..	4.962	..	5.350	..	5.722	..	6.416	..	7.019	..	7.569	..	8.629	..	20
21	..	..	5.294	..	5.723	..	6.071	..	6.811	..	7.523	..	8.147	..	9.231	..	21
22	..	..	5.613	..	6.100	..	6.532	..	7.332	..	8.037	..	8.680	..	9.845	..	22
23	..	..	5.947	..	6.459	..	6.920	..	7.783	..	8.588	..	9.277	..	10.547	..	23
24	..	..	6.283	..	6.841	..	7.334	..	8.239	..	9.086	..	9.827	..	11.182	..	24
25	..	..	..	..	7.204	..	7.752	..	8.716	..	9.621	..	10.385	..	11.827	..	25
26	..	..	..	..	7.578	..	8.148	..	9.198	..	10.162	..	10.985	..	12.563	..	26
27	..	..	..	..	7.952	..	8.570	..	9.684	..	10.682	..	11.579	..	13.227	..	27
28	..	..	..	..	..	..	8.993	..	10.174	..	11.214	..	12.216	..	13.900	..	28



29	9 393	6 4	10 667	7 8	11 771	9 4	12 800	10 5	14 666	12 6	29
30	9 818	6 8	11 163	8 3	12 332	10 0	13 450	11 2	15 355	13 6	30
31			11 661	8 8	12 897	10 6	14 046	11 9	16 051	14 6	31
32			12 126	9 3	13 467	11 2	14 647	12 7	16 843	15 7	32
33			12 627	9 8	14 039	11 8	15 313	13 5	17 554	16 8	33
34			13 130	10 4	14 615	12 4	15 923	14 3	18 272	17 9	34
35			13 633	11 0	15 194	13 0	16 599	15 1	19 087	19 1	35
36			14 137	11 7	15 775	13 7	17 217	16 0	19 817	20 3	36
					16 358	14 5	17 838	16 9	20 553	21 5	37
					16 943	15 3	18 525	17 8	21 387	22 7	38
					17 480	16 1	19 153	18 7	22 134	23 9	39
					18 067	16 9	19 845	19 6	22 886	25 2	40
					18 654	17 7	20 477	20 5	23 737	26 5	41
					19 242	18 5	21 112	21 4	24 498	27 8	42
							21 811	22 4	25 263	29 1	43
							22 448	23 4	26 129	30 5	44
							23 150	24 4	26 901	31 9	45
							23 789	25 5	27 678	33 3	46
							24 493	26 6	28 555	34 7	47
							25 133	27 6	29 337	36 1	48
									30 122	37 5	49
									31 008	38 9	50
									31 798	40 3	51
									32 590	41 7	52
									33 483	43 2	53
									34 278	44 7	54
									35 075	46 2	55
									35 972	47 7	56
									36 771	49 2	57
									37 570	50 8	58
									38 470	52 4	59
									39 270	54 0	60

### Tank Calibration Table

For standard tank in horizontal position, radius of heads equal to diameter of tank.

$C$  = cu. ft. per ft. of length of tank cylinder.

$Vh$  = cu. ft. of volume of heads.

$L$  = length of cylinder in feet.

Total volume at any depth of liquid in tank =  $CL \pm Vh$ , the sign depending upon whether the heads are concave or convex.

For example, a 6 X 20 ft. tank has 30 in. of liquid. Read opposite 30 in. under 6 ft. diameter.  $C = 11 163$  and  $Vh = 8 3$ . The volume of liquid then equals  $11 163 \times 20 + 8 3 = 231 6$  cu. ft.

If the tank is more than half full, the volume of the empty space is subtracted from the total volume of the tank. For example, a 5 X 20 ft. tank, convex heads, contains 52 in. of liquid. Total volume =  $(9 818 \times 20 + 6 8) \times 2 = 406 3$  cu. ft. Opposite 8 in. under 5 ft. diameter.  $C = 1 551$  and  $Vh = 0 4$ . Then volume of liquid =  $406 3 - (1 551 \times 20 + 0 4) = 374 9$  cu. ft.

From *Chem. and Met. Eng.*, May, 1927.

# SECTION VIII

## FUELS AND REFRACTORIES

CALORIFIC AND EVAPORATIVE VALUES OF VARIOUS LIQUID FUELS

	Sp. gr.	Flash point, °F.	Calorific value by bomb, calories	Actual evaporation from and at 212°F.
American residuum..	0.886	350	10,904	15 0
Russian Astatki. <sup>1</sup> ..	0.956	308	10,800	14 8
Texas.....	0.945	244	10,700	14 79
Burma.....	0.920	230	10,480	14 5
Borneo.....	0.936	285	10,461	14 0
Mexican crude.....	0.950	290	10,500	14 90
Oklahoma....	0.863	.....	10,800	.....
Roumanian residue.	0.946	.....	10,500	.....
Trinidad crude	0.945	.....	10,200	.....
California.....	0.962	.....	10,400	.....
Shale oil.....	0.875	288	10,120	13 8
Blast furnace oil.	0.979	206	8,933	12 0
Heavy tar oil....	1.084	218	8,916	12 0
Gasoline.....	0.7100	.....	11,733	.....
Ohio crude.....	0.8048	.....	11,149	.....

<sup>1</sup> Specially compiled for "The Petroleum Year Book, 1914 "

BAUMÉ GRAVITY AND CORRESPONDING SPECIFIC GRAVITIES  
WEIGHTS PER GALLON AND CALORIFIC POWER OF OIL<sup>1</sup>

Baumé°	Specific gravity	Pounds in a gallon	Calculated B.t.u. per pound	Calculated B.t.u. per gallon	Remarks
14	0.9722	8.10	18,810	152,361	Mexico, California, Texas and Kansas crudes, fuel oil
15	0.9655	8.05	18,850	151,743	
16	0.9589	7.99	18,890	150,931	
17	0.9523	7.94	18,930	150,304	
18	0.9459	7.88	18,970	149,484	
19	0.9395	7.83	19,010	148,848	
20	0.9333	7.78	19,050	148,209	
21	0.9271	7.73	19,090	147,506	
22	0.9210	7.68	19,130	146,918	
23	0.9150	7.63	19,170	146,267	
24	0.9090	7.58	19,210	145,612	Kansas, Indian Territory and Illinois crudes, Penn'a. fuel, California refined fuel oil
25	0.9032	7.54	19,250	145,145	
26	0.8974	7.49	19,290	144,482	
27	0.8917	7.44	19,330	143,815	
28	0.8860	7.39	19,370	143,144	
29	0.8805	7.34	19,410	142,469	
30	0.8750	7.29	19,450	141,790	
31	0.8695	7.25	19,490	141,303	
32	0.8641	7.21	19,530	140,811	
33	0.8588	7.16	19,570	140,121	Ohio, Penn'a. and West Virginia crude, California and Kansas refined fuel oil
34	0.8536	7.12	19,610	139,623	
35	0.8484	7.07	19,650	138,926	
36	0.8433	7.03	19,690	138,421	
37	0.8383	6.99	19,730	137,913	
38	0.8333	6.95	19,770	137,402	
39	0.8284	6.91	19,810	136,887	
40	0.8235	6.87	19,850	136,370	
41	0.8187	6.83	19,890	135,849	
42	0.8139	6.80	19,930	135,524	Kerosene and gasoline
43	0.8092	6.76	19,970	134,997	
44	0.8045	6.72	20,010	134,467	
45	0.8000	6.68	20,050	133,934	
46	0.7954	6.64	20,090	133,398	
47	0.7909	6.60	20,130	132,858	
48	0.7865	6.57	20,170	132,517	
49	0.7821	6.53	20,210	131,971	
50	0.7777	6.49	20,250	131,423	

<sup>1</sup> From "Fuel Oil Data," TATE-JONES & Co., Inc., furnace engineers, based on SHERMAN and KRAFFT's formula:

$$\text{B.t.u.} = 18,850 + 40 (\text{Bé.}^\circ - 10)$$

*Journ. Am. Chem. Soc.*, October, 1908.

LIMITS OF FUEL ANALYSES—UNITED STATES<sup>1</sup>

	H <sub>2</sub> O	Ash	Sulphur	C	H	O + N	Calories
Peat.....	6.00-19.7	3.2-36.0	0.19-1.94	.....	.....	.....	2867-5161
Brown coal.....	5.8-14.0	1.7-14.7	0.63-2.20	53-70	3.6-7.4	10.8-23.9	4700-8000
Bituminous.....	0.6-5.2	6.1-14.7	0.90-4.5	60.5-78.8	4.8-5.2	9.1-15.4	6000-8000
Anthracite.....	0.5-2.5	1.0-?	.....	91-93	0.0-3.0	0.0-3.0	7000
Coke <sup>2</sup> .....	0.15-1.2	3.8-11.5	0.6-1.6	87-93	0.4-3.0	.....	.....

<sup>1</sup> SOMMERBIER'S "Coal"<sup>2</sup> Compressive strength of 600-2000 lb. per square inch, hardness of 2.5-3. These values from private notes on Eastern coals.TYPICAL GAS ANALYSES<sup>1</sup>

	CO	Vol. hyd. carb.	N	CO <sub>2</sub>	H
Producer gas.....	23.7-33.6	1.3-11.9	49.5-67.1	0.45-5.30	1.25-9.7 <sup>2</sup>
Mond gas.....	10.3-11.0	2.0-5.3	43.0-55.8	14.6-16.5	23.5-27.5
Iron-furnace gas.....	20.0-32.0	0.0-0.6	55.0-65.0	6.0-18.0	1.0-6.0
Water gas (blow up).....	23.7-32.2	0.18-0.44	63.9-65.9	1.6-7.0	2.1-2.95
Water gas (true).....	40.9-45.2	0.2-1.1	1.9-7.1	1.8-5.6	44.8-51.4
Oil gas.....	0.6-1.8	28.5-77.3	0	1.3	18.9-68.5

<sup>1</sup> HOFMAN'S "General Metallurgy."<sup>2</sup> Using steam

OXYGEN AND AIR REQUIRED FOR PERFECT COMBUSTION<sup>1</sup>

1 kilogram	Requires kilograms		Product of combustion		Nitrogen in original air kilograms
	Oxygen	Dry air	Composition	Kilograms	
C. . . . .	1.333	5.777	CO	2.333	4.444
C. . . . .	2.667	11.555	CO <sub>2</sub>	3.667	8.888
CO. . . . .	0.571	2.472	CO <sub>2</sub>	1.571	1.901
H. . . . .	8.000	34.664	H <sub>2</sub> O	9.000	26.664
CH <sub>4</sub> . . . . .	4.000	17.332	CO <sub>2</sub> , H <sub>2</sub> O	2.750, 2.250	13.332
C <sub>2</sub> H <sub>4</sub> . . . . .	3.429	14.848	CO <sub>2</sub> , H <sub>2</sub> O	3.143, 1.286	11.419
Fe . . . . .	0.286	1.238	FeO	1.286	0.952
Fe . . . . .	0.429	1.857	Fe <sub>2</sub> O <sub>3</sub>	1.439	1.428
Si. . . . .	1.143	5.064	SiO <sub>2</sub>	2.143	3.921
P. . . . .	1.290	5.586	P <sub>2</sub> O <sub>5</sub>	2.290	4.296
Mn . . . . .	0.291	1.221	MnO	1.291	0.969
S . . . . .	1.000	4.333	SO <sub>2</sub>	2.000	3.333

<sup>1</sup> From HOFMAN's "General Metallurgy."Theoretical Maximum Combustion Temperatures<sup>1</sup>

Oxyhydrogen flame. . . . .	3191°C.
Hydrogen and dry air . . . . .	2010°C.
Hydrogen and dry air in 25 per cent. excess . . . . .	1764°C.
Carbon monoxide with cold air . . . . .	2050°C.
CO and air, both at 700°C . . . . .	2284°C.
Natural gas and air . . . . .	1806°C.
Natural gas with air at 1000°C . . . . .	2288°C.
Thermit (2Al + Fe <sub>2</sub> O <sub>3</sub> ) . . . . .	2694°C.

COMPARATIVE MOISTURE IN DIFFERENT FUELS<sup>1</sup>  
Moisture Content when New

Fuel	Moisture, per cent.	Remarks
Wood. . . . .	30-60	Green wood.
Peat. . . . .	50-90	As dug.
Lignite. . . . .	30-45	As mined.
Bituminous coal. . . . .	2-25	As mined.
Semi-bituminous coal . . . . .	1- 5	As mined.
Anthracite coal. . . . .	1- 3	As mined

<sup>1</sup> SOMERMEIER'S "Coal "<sup>1</sup> J. W. RICHARD'S "Metallurgical Calculations," Vol I, pp. 36-39.

# 536 METALLURGISTS AND CHEMISTS' HANDBOOK

## COMPOSITION AND HEATING VALUE OF AIR-DRIED MATERIALS

	Wood	Peat <sup>1</sup> Florida	Lignite, <sup>2</sup> North Dakota	Bituminous		Penna., <sup>4</sup> Pittsburgh	Semi-bit., <sup>3</sup> New River	Anthra- cite, <sup>3</sup> Penna.
				Illinois <sup>2</sup>	Ohio, <sup>3</sup> Hock- ing			
<i>Proximate</i>								
Moisture.....	20.00	21.00	16.70	5.13	3.00	1.00	0.76	2.08
Volatile.....		51.72	37.10	32.68	39.00	35.00	20.54	7.27
Fixed carbon....		22.11	39.49	47.46	50.50	57.85	73.61	74.32
Ash.....		5.17	6.71	14.73	7.50	6.15	5.09	16.33
		100.00	100.00	100.00	100.00	100.00	100.00	100.00
<i>Ultimate</i>								
Carbon....	40.0	46.57	55.16	60.51	70.70	78.75	82.41	75.21
Hydrogen..	7.2	6.51	5.61	4.88	5.20	5.14	4.38	2.81
Nitrogen..	0.8	2.33	0.91	1.23	1.30	1.55	1.05	0.80
Oxygen...	50.7	38.97	30.98	14.20	11.95	7.56	5.87	4.08
Sulphur...		5.17	0.63	4.45	3.35	0.90	1.20	0.77
Ash.....	1.3	0.45	6.71	14.73	7.50	6.10	5.09	16.33
	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00
<i>Determined</i>								
Calorific value.	4200	4515	5273	6199	7155	7865	8254	6929
<i>Calculated</i>								
Calorific value.	...	4338	5071	6059	7100	7845	7942	6886

(See p. 541 for English Coals and Charcoal)

<sup>1</sup> U. S. G. S., *Bull.* 332

<sup>2</sup> U. S. G. S., *Professional Paper*, 48.

<sup>3</sup> Ohio G. S., *Bull.* 9.

<sup>4</sup> U. S. G. S., *Bull.* 290.

### BUNSEN BURNER TEMPERATURES (USING AIR)

Acetylene, C <sub>2</sub> H <sub>2</sub>	2400°C.
Hydrogen, H <sub>2</sub>	1900°C.
Average illuminous gas	1780°C.
Average water gas	1775°C.
Average coke oven gas	1300°C.

### Calculation of Theoretical Maximum Temperatures of Combustion<sup>1</sup>

An algebraic method of calculating the theoretical maximum rise in temperature is to calculate the total thermal capacities of the products of combustion in terms of  $t$ , the temperature. This amount must be equal to the heat available to raise the temperature.

Thus, what would be the maximum temperature possible burning carbon with air (calculate on 100 per cent. excess of oxygen).

<sup>1</sup> G. G. BROWN, *Chem and Met. Eng.*, Sept. 6, 1922.

1 lb. C + 62.88 cu. ft. O<sub>2</sub> + 236.4<sup>1</sup>/<sub>2</sub> cu. ft. N<sub>2</sub> → 31.44 cu. ft. CO<sub>2</sub> + 31.44 cu. ft. O<sub>2</sub> + 236.4 cu. ft. N

	Cu. ft.	Thermal capacities (0 - t°F.)
CO <sub>2</sub> .....	31.44	(0.227t + 0.385t <sup>2</sup> × 10 <sup>-5</sup> )
O <sub>2</sub> .....	31.44	(0.1786t + 0.883t <sup>2</sup> × 10 <sup>-6</sup> )
N <sub>2</sub> .....	236.4	(0.0786t + 0.883t <sup>2</sup> × 10 <sup>-6</sup> )

$$\begin{aligned}\text{Total thermal capacity} &= 5.694t + 0.357t^2 \times 10^{-3} \\ 14,580 &= 5.694t + 0.000357t^2 \\ t &= \pm 2250, \therefore t = 2250^\circ\text{F.}\end{aligned}$$

**Mean  $C_p$  (0 to t°C.) in Calories per Gram Mol**

$$\begin{aligned}\text{Diatomic gases (N}_2, \text{O}_2, \text{CO)} &= 6.9 + 0.00042t. \\ \text{CO}_2 \text{ (up to } 1250^\circ\text{C.)} &= 8.8 + 0.00024t. \\ \text{CO}_2 \text{ (above } 1250^\circ\text{C.)} &= 10.02 + 0.00072t. \\ \text{H}_2\text{O} &= 7.8 + 0.00175t.\end{aligned}$$

**Mean  $C_p$  (0 to t°F.) in B.t.u. per Pound Mol**

$$\begin{aligned}\text{Diatomic} &= 6.88 + 0.000234t. \\ \text{CO}_2 \text{ (up to } 2300^\circ\text{F.)} &= 8.7 + 0.00135t. \\ \text{CO}_2 \text{ (above } 2300^\circ\text{F.)} &= 10 + 0.0004t. \\ \text{H}_2\text{O} &= 7.75 + 0.001t.\end{aligned}$$

**Mean  $C_p$  [t to (t + x) °C.] in Calories per Gram Mol**

$$\begin{aligned}\text{Diatomic gases} &= 6.9 + 0.00084t + 0.00042x. \\ \text{CO}_2 \text{ (up to } 1250^\circ\text{C.)} &= 8.8 + 0.0048t + 0.0024x. \\ \text{CO}_2 \text{ (above } 1250^\circ\text{C.)} &= 10.02 + 0.00144t + 0.00072x. \\ \text{H}_2\text{O} &= 7.8 + 0.0035t + 0.00175x.\end{aligned}$$

**Mean  $C_p$  [t to (t + x) °F.] in B.t.u. per Pound Mol**

$$\begin{aligned}\text{Diatomic gases} &= 6.88 + 0.000468t + 0.000234x. \\ \text{CO}_2 \text{ (up to } 2300^\circ\text{F.)} &= 8.7 + 0.0027t + 0.00135x. \\ \text{CO}_2 \text{ (above } 2300^\circ\text{F.)} &= 10 + 0.0008t + 0.0004x. \\ \text{H}_2\text{O} &= 7.75 + 0.002t + 0.001x.\end{aligned}$$

Any of the expressions given above may be converted to mean  $C_p$  over the same temperature range by subtracting 1.985, or more simply 2, from the constant term.

To convert from calories per gram mol to calories per gram, or from B.t.u. per pound mol to B.t.u. per pound, divide the entire expression by the molecular weight of the gas.

The above equations for calories per grams mol may be converted to calories per liter, or Calories (kilogram cal.) per cubic meter at 0°C. and 760 mm. by dividing the entire expression by 22.4. The equation for B.t.u. per pound mol may be converted to B.t.u. per cu. ft. at 60°F. and 30 in. by dividing the entire expression by 378.

**Inflammability of Carbonaceous Dusts**

Many carbonaceous dusts form highly explosive mixtures when suspended in air. R. V. WHEELER<sup>1</sup> classes dusts as follows:

I.—Dusts which ignite and propagate flame readily, the source of heat required for ignition being comparatively small, for example, a lighted match.

II.—Dusts which are readily ignited but which, for the propagation of flame, require a source of heat of large size and high temperature, such as an electric arc, or of long duration, such as the flame of a Bunsen burner.

III.—Dusts which do not appear to be capable of propagating flame under any conditions likely to obtain in a factory, because (a) they do not readily form a cloud in air, or (b) they are contaminated with a large quantity of incombustible matter, or (c) the material of which they are composed does not burn rapidly enough.

CLASS I	{	Sugar	Grain (flour mill)
		Starch	Maize
		Rice meal and sugar refuse	Grain (grain storage)
		Wood flour	Rape seed
		Malt	Corn flour
		Oat husk	Flour (flour mill)
CLASS II	{	Rice milling	Grist milling
		Castor oil meal	Horn meal
		Offal grinding (bran)	Mustard
CLASS III	{	Spice milling	Sack cleaning
		Cottonseed	Rape seed (Russian)
		Cottonseed and soya bean	Grain cleaning

H. H. BROWN worked out the explosiveness as compared to standard Pittsburgh coal dust (*Journ. Ind. and Eng. Chem.* March, 1917, p. 269) their explosivities being roughly in proportion to the pressures generated under the standard conditions of his experiments (see original paper for details).

The comparison shows a high degree of explosiveness for most dusts, and it should be noted that most of them will ignite at a low red heat.

<sup>1</sup> Report on the Inflammability and Capacity for Transmitting Explosions of Carbonaceous Dust Liable to be Generated on Premises, under the Factory and Workshop Acts, 1913. R. V. WHEELER, D.Sc.



## INFLAMMABILITY OF CARBONACEOUS DUSTS

		Pressure generated lb. per sq. in.
Kind of dust		
	Lycopodium.....	17.5
	Stinking smut of wheat.....	13.9 to 15.9
	Yellow dust from first break in dry milling.....	15.2
	Dextrin dust from dextrin kiln.....	12.8 to 14.6
	Powdered wheat starch.....	14.0
	Starch dust (corn) from dry starch kilns.....	12.5 to 13.8
	Canary dextrin.....	11.8 to 13.8
(200 mesh)	Tan bark dust.....	13.3
	Powdered corn starch.....	13.2
	Wheat starch.....	11.0 to 13.1
	Starch and dextrin dust from about tray filler.....	13.0
(200)	Wheat elevator dust, side wall.....	13.0
(200)	Wood dust from chipper room.....	12.8
(200)	Oat and corn dust from unloading station.....	12.4 to 12.6
	White corn dust, top of elevator.....	11.0 to 12.5
(200)	Wheat elevator dust.....	12.5
(100)	Oat dust from ground oat hulls.....	12.3
	Sugar, lump pulverized to pass 200 mesh.....	12.2
	Gluten feed dust, from beams, etc., in cur- ing room.....	12.1
(200)	Oat dust from feed oats.....	12.0
(200)	Feed dust from dust collector.....	11.8
	Potato flour.....	11.7
	Sugar dust from sugar pulverizer.....	11.7
	Rice starch.....	9.0 to 11.3
(200)	Wheat flour from packing room.....	9.3 to 11.2
	Malt dust from discharge of collecting system.....	10.6
	Wheat flour dust, rolls and purifiers.....	10.5
(200)	Fertilizer dust, from grinding dry tankage.....	10.5
	Tapioca flour.....	9.9 to 10.4
	Sugar dust, collector from powder mills.....	10.3
	Pittsburgh Standard Coal Dust.....	10.1
	Tan bark dust.....	10.0
	Cocoa dust from cocoa bolters.....	9.9
	Reduction middlings.....	9.4

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### INFLAMMABILITY OF CARBONACEOUS DUSTS

	Kind of dust	Pressure generated lb. per sq. in.
	Cocoa dust from cocoa cooling room	9.1
	Extra fine sulphur flour.....	8.8
	Wheat smut and filed dust.....	8.8
	Ground cork dust.....	7.4
	Rice flour.....	5.6
(200)	Arrowroot powder. ....	3.9
	Potato starch.....	3.2
	Gelatin dust from elevator.....	1.1

### SUSPENDED DUSTS—LOWER EXPLOSIVE LIMITS

(In Milligrams per Liter of Air)

Dust	Glowler	Arc	Induction spark
Starch.....	7	10.3	13.7
Corn elevator....	10.3	10.3	13.7
Wheat elevator. *	10.3	10.3	No "good propagation"
Sulphur.....	7.0	13.7	13.7
Sugar.....	10.3	17.2	34.4
Aluminum. ....	7.0	7.0	13.7
Coal.....	17.2	24.1	No ignition

### Mineral Oils—General Composition<sup>1</sup>

The characteristics of crude mineral oils and their products vary greatly in different localities; but the following general information may be of interest.

	Gravity, deg. B6.	Flash point, deg. F.	Burning point, deg. F.
Crude oil.....	12-45	110-200	120-220
Kerosene.....	40-50	90-125	105-150
Distillate (gas oil).	28-38	100-250	110-325
Fuel oil.....	22-28	100-300	125-375
Residuum.....	10-20	125-500	200-600

The heat value of mineral oils and their products may be very closely determined from their gravity, by the following formula:

$$\text{B.t.u. per pound} = 18,650 + \{40(\text{Baumé} - 10)\}$$

(SHERMAN AND KRAPFF)

<sup>1</sup> "The Diesel Engine," BUSCH-SULZER BROS. Diesel Engine Co. †

ULTIMATE COMPOSITION OF CRUDE OILS<sup>1</sup>

	Sp. gr.	C	H	O
Pennsylvania.....	0.886	84.9	13.7	1.4
Russia (Balachny).....	0.884	87.4	12.5	0.1
Russia (Balachny residuum).....	0.928	87.1	11.7	1.2
Borneo.....	0.945	87.8	10.78	1.24
Texas.....	0.936	85.66	11.03	3.31
Burma.....	0.920	86.4	12.1	1.5

<sup>1</sup> From "The Petroleum Year Book, 1914."

**Charcoal Analysis.**—According to J. E. JOHNSON, JR., the average analysis of kiln birch and maple charcoal is as follows: CO<sub>2</sub>, 4.50 per cent.; O<sub>2</sub>, 0.67; H<sub>2</sub>, 1.65; CO, 11.10; CH<sub>4</sub>, 3.40; N<sub>2</sub>, 7.77; fixed carbon, 68.50; ash, 1.00 per cent. Retort charcoal is commonly believed to be a little higher in fixed carbon.

COAL<sup>1</sup>—ULTIMATE ANALYSIS

	Sp. gr	C	H	O	S	Ash	H <sub>2</sub> O
Welsh.....	1.315	83.8	4.8	1.0	1.4	4.1	4.9
Newcastle.....	1.256	82.1	5.3	1.3	1.2	5.7	3.8
Lancashire.....	1.273	77.9	5.3	1.3	1.4	9.5	4.6

<sup>1</sup> "Petroleum Year Book," 1914

## COMMERCIAL SIZES OF ANTHRACITE

Grade	Size of screen, inches		Wt. per cu ft., lb.	1 cu. ft. solid coal gives, cu. ft.
	On	Through		
Lump.....	4½ - 9	.....	57.0	1.614
Broken.....	2¾ - 27/8	3¼ - 4½	53.0	1.755
Egg.....	1¾ - 2¼	2¾ - 27/8	52.0	1.769
Large stove.....	1¼ - 17/8	1¾ - 2¼	51.5	1.787
Small stove.....	1 - 1¼	1¼ - 17/8	51.25	1.795
Chestnut.....	5/8 - ¾	1 - 1¼	51.00	1.804
Pea.....	¾ - 5/8	5/8 - 7/8	50.75	1.813
No. 1 Buckwheat.....	¾ - 7/8	7/8 - 5/8	50.75	1.813
No. 2 Buckwheat.....	.....	¾ - 3/8	50.75	1.813

## Shale Oil

These oils are secured by the distillation of shales. Two typical shale analyses are given by SEXTON as follows: (1)

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Volatile matter, 34.96 per cent.; fixed carbon, 7.54 per cent.; ash, 57.5 per cent. (2) Volatile matter, 13.5 per cent.; fixed carbon, 2.5 per cent.; ash, 84 per cent.<sup>1</sup>

### TYPICAL GAS ANALYSES<sup>1</sup> (BY VOLUME)

	Natural gas Ohio	Coal gas	Producer gas	Water gas	Mond gas
Hydrogen . . . . .	1.89	51.8	8.0	49.17	27.2
Carbon monoxide . . .	0.2	9.1	23.7	43.75	11.0
Marsh gas . . . . .	92.84	31.8	2.2	0.31	1.8
Ethane . . . . .	0.35	5.2			0.4
Nitrogen . . . . .	3.82	2.1	61.5	4.00	42.5
Carbon dioxide . . .	0.75		4.1	2.71	17.1

### KINDLING TEMPERATURES OF FUELS<sup>1</sup>

Solid	Deg C	Gaseous	Oxygen	Air
Dry peat . . . . .	225	Hydrogen . . . . .	585	580-590
Bituminous coal . . .	326	Carbon monoxide, moist . . .	651	644-658
Pine wood . . . . .	395	Ethylene . . . . .	543	542-547
Charcoal, made at 350°C . . . . .	360	Acetylene . . . . .	429	406-440
Charcoal, made at 1250°C . . . . .	650	Hydrogen sulphide . . . . .	364	
Anthracite . . . . .	700	Methane . . . . .	650-750	650-750
Coke . . . . .	700	Ethane . . . . .	520-630	
Mine timbers . . . . .	200-400	Benzene . . . . .		406-440
Lignite dust . . . . .	150	Illuminating gas . . . . .		580-590
		Water gas . . . . .		644-658
		Enriched producer gas . . . . .		644-658
		Propane . . . . .	547	
		Propylene . . . . .	504	
		Cyanogen . . . . .	810	850-862

<sup>1</sup> DIXON and COWARD, *Journ. Chem. Soc. of London*, 1910, p. 514.

### Calorific Power of Fuels

Let  $H$  represent the percentage of hydrogen in a fuel;  $C$  represent the percentage of carbon;  $O$  the oxygen;  $S$  the sulphur; and assume also that the water formed by the combustion, represented by  $H_2O$ , does not condense (which it usually does not in metallurgical operations).

DULONG'S formula for calorific power of a fuel then is:

$$C.P. = \frac{8,100C + 34,500\left(H - \frac{O}{8}\right) + 2,250S - 537H_2O}{100}$$

An empirical formula adopted by German engineers is:

$$C.P. = \frac{8,100C + 29,000\left(H - \frac{O}{8}\right) + 2,500S - 600H_2O}{100}$$

<sup>1</sup> SEXTON, "Fuel and Refractory Materials."

FRACTIONS OF AVERAGE COAL TAR AND THEIR USES<sup>1</sup>

First crude separation by distillation.	Light oil.	Middle oil (or dead oil).	Heavy oil (including anthracene oil).	Pitch.
Temperatures of distillation.	70°-160°C	160°-230°C.	230°-360°C.	Above 360°C.
Percentage in tar.	3	8	24	65
Intermediate products, by distillation or expression.	Benzene, toluene, xylene, etc.; phenol.	Phenol, cresols, etc.; naphthalene, heavy hydrocarbons	Cresols, naphthalene, anthracene; heavy hydrocarbons quinoline bases.	Soft pitch, hard pitch.
Crude commercial products and their uses.	"Benzol" and solvent naphtha for solvents, paint thinners, motor fuel, gas enrichment.	Cresote oil. Lamp black. Disinfectants.	Road oils, impregnation of timber.	Pitch, briquetting, protective paints.
Intermediate chemical products.	Nitrobenzene, aniline salts, aniline oil, carbolic acid.	Carbolic acid, picric acid, phthalic acid, naphthols, naphthylamines, salicylic acid.	Anthraquinone, alizarin.	Roofing tars. Paving tars.
Refined chemical products, dyes, etc., and their uses	Nitrotoluenes, diphenylamine and other ingredients of explosives; aniline dyes, hydroquinone and other photographic developers; drugs and medicines	Picric acid, picrates, and other nitrocompounds for explosives; naphthol dyes, and colors, artificial indigo, refined carbolic acid.	Alizarin dyes.	

<sup>1</sup> Bur. Mines, *Tech. Paper* 89.

**Inflammability of Gaseous Mixtures—Determination of the Dilution Limits.**<sup>1</sup>—The results, given by previous workers varied over a considerable range. The authors define a gaseous mixture as inflammable at a stated temperature and pressure if it will propagate flame indefinitely when the unburnt portion of the mixture is kept at that temperature and pressure. Combustion in an inflammable mixture is not necessarily complete. In order to conform to this definition, the flame is started near the bottom of a tall vessel which is of sufficient cross-section to minimize the cooling influence of the walls, and the bottom of the vessel is sealed in water so that the pressure cannot rise appreciably. Upward flame propagation is adopted since in very weak mixtures the velocity of propagation may be less than that of the upward convection currents and downward

<sup>1</sup> H. F. COWARD and G. W. JONES, *Bur. Mines Bull.* 279.

propagation of the flame may thus be prevented. Under these conditions the following minima were found:

APPROXIMATE LIMITS OF INFLAMMABILITY OF SINGLE GASES AND VAPORS IN AIR AT ORDINARY TEMPERATURES AND PRESSURES SATURATED WITH  $H_2O$  AT ABOUT  $17-18^{\circ}C$ .<sup>1</sup>

	Lower limit, by volume, per cent.	Higher limit, by volume, per cent.		Lower limit, by volume, per cent.	Higher limit, by volume, per cent.
Hydrogen.....	4.1	74	Toluene.....	1.3	
Ammonia.....	16	27	Methyl alcohol..	6	
Hydrogen sulphide	4.3	46	Ethyl alcohol...	3.5	19
Carbon disulphide.	1	50	Ethyl ether.....	1.7	
Carbon monoxide..	12.5	74	Acetaldehyde...	4	57
Methane.....	5.3	14	Acetone.....	2 or 3	13
Methane (turbu- lent mixture)...	5.0	15	Methyl ethyl ketone.....	2	12
Ethane.....	3.2	12.5	Ethyl formate...	3.5	16.5
Propane.....	2.4	9.5	Methyl acetate..	4.1	14
Butane.....	1.9	8.5	Ethyl acetate...	2.2	11.5
Pentane.....	1.4	8	Ethyl nitrite...	3	
Ethylene.....	3.3		Dichloroethylene	10	13
Acetylene.....	2.5		Pyridine.....	1.8	12.5
Benzene.....	1.4	8			

<sup>1</sup> From *Bur. Mines Bull.* 279 (by H. F. COWARD and G. W. JONES).

COMPOSITION OF THE RESIDUAL ATMOSPHERE PRODUCED BY FLAMES<sup>1</sup>

Substance burnt	Composition of residual atmosphere in which flame was extinguished		
	O <sub>2</sub> , per cent.	N <sub>2</sub> , per cent.	CO <sub>2</sub> , per cent.
Alcohol.....	14.9	80.7	4.35
Methylated spirit..	15.6	80.2	4.15
Paraffin oil.....	16.6	80.4	3.0
Colza and paraffin .	16.4	80.5	3.1
Candles.....	15.7	81.1	3.2
Hydrogen.....	5.5	94.5	.....
Carbon monoxide...	13.4	74.4	12.2
Methane.....	15.6	82.1	2.3
Coal gas.....	11.4	83.7	4.9

<sup>1</sup> *Journ. Soc. Chem. Ind.*, Feb. 27, 1915.

### Coal Burned per Square Foot of Grate in Reverberatory Furnaces<sup>1</sup>

Hand reverberatory roasting furnace.....	3 to 8 lb.
Agglomerating or lead-reverberatory smelting furnace.....	12 to 16 lb.
Copper-reverberatory smelting furnace .....	16 to 30 lb.
Puddling furnace.....	20 to 30 lb.
Heating furnace.....	30 to 40 lb.
Locomotive boilers (induced draft) .....	80 to 100 lb.

### Ratio of Areas of Total Grate to Air Space<sup>2</sup>

Coke.....	3:1 to 2:1
Bituminous coal.....	3:3:1 to 2:1
Brown coal.....	5:1 to 3:1
Peat or wood.....	7:1 to 5:1

### Combustion Data

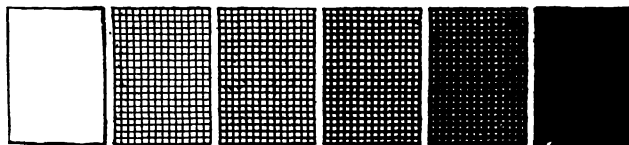
(Good Modern Practice)

1 lb. coal average.....	13,500 B.t.u.
1 lb. coal $(13,500 \times 778) \div (60 \times 33,000)$ ...	5.3 hp.-hours.
Lost through grates.....	1.00 per cent.
Lost boiler radiation.....	5.00 per cent.
Lost chimney gases.....	22.00 per cent.
Lost main pipes radiation.....	1.56 per cent.
Lost auxiliary pipes radiation .....	0.22 per cent.
Lost auxiliary exhaust .....	1.40 per cent.
Lost engine radiation.....	2.08 per cent.
Lost engine exhaust .....	57.31 per cent.

Total loss .....	90.57 per cent.
Converted to power. "	9.43 per cent.

### Ringelmann's Smoke Chart

The following chart is convenient for estimating the density of smoke from chimneys, both as a check on the completeness of combustion and as evidence in case certain chimneys are












attacked as nuisances by owners of property near metallurgical plants. (Use this chart at arms length. The original is a chart 3 × 24 in., supposed to be posted about 50 ft. away.)

<sup>1</sup> GRÜNER, "Traité de Metallurgie Générale."

<sup>2</sup> Leitfader to Eisenhüttenkunde, 1898, p. 104.

Standard Fire Brick Shapes<sup>1</sup>

Name	Dimensions	
9 in.	$9 \times 4\frac{1}{2} \times 2\frac{1}{2}$	
Soap	$9 \times 2\frac{1}{2} \times 2\frac{1}{4}$	
No. 1 Split	$9 \times 4\frac{1}{2} \times 1\frac{1}{4}$	
No. 2 Split	$9 \times 4\frac{1}{2} \times 2$	
9-in. large	$9 \times 6\frac{3}{4} \times 2\frac{1}{2}$	
9-in. small	$9 \times 3\frac{1}{2} \times 2\frac{1}{2}$	
No. 1 Key	$9 \times 4\frac{1}{2} - 4 \times 2\frac{1}{2}$ : 12 ft. diam. inside. 112 brick to circle.	
No. 2 Key	$9 \times 4\frac{1}{2} - 3\frac{1}{2} \times 2\frac{1}{2}$ : 6 ft. diam. inside. 65 brick to a circle.	
No. 3 Key	$9 \times 4\frac{1}{2} - 3 \times 2\frac{1}{2}$ : 3 ft. diam. inside. 41 brick to a circle.	
No. 4 Key	$9 \times 4\frac{1}{2} - 2\frac{1}{4} \times 2\frac{1}{2}$ : 18 in. diam. inside. 26 brick to a circle.	
No. 1 Wedge <sup>2</sup>	$9 \times 4\frac{1}{2} \times 2\frac{1}{2} - 2$ : 5 ft. diam. inside. 102 brick to a circle.	
No. 2 Wedge <sup>2</sup>	$9 \times 4\frac{1}{2} \times 2\frac{1}{2} - 1\frac{1}{2}$ : 2 ft. 6 in. diam. inside. 63 brick to a circle.	
No. 1 Arch	$9 \times 4\frac{1}{2} \times 2\frac{1}{2} - 2$ : 4 ft. diam. inside. 72 brick to a circle.	
No. 2 Arch	$9 \times 4\frac{1}{2} \times 2\frac{1}{2} - 1\frac{1}{2}$ : 2 ft. diam. inside. 42 brick to a circle.	
No. 3 Arch	$9 \times 4\frac{1}{2} \times 2\frac{1}{2} - 1$ : 6 in. diam. inside. 19 brick to a circle.	
Side Skew	$9 \times 4\frac{1}{2} - 1\frac{3}{4} \times 2\frac{1}{2}$	
End Skew	$9 \times 7 \times 4\frac{1}{2} \times 2\frac{1}{2}$	
Skewback	$9 \times 4\frac{1}{2} - 1\frac{1}{2} \times 2\frac{1}{2}$	
No. 1 Neck	$9 - 4\frac{1}{2} \times 4\frac{1}{2} \times 2\frac{1}{2}$	
No. 2 Neck	$9 - 2 \times 4\frac{1}{2} \times 2\frac{1}{2}$	
No. 3 Neck <sup>2</sup>	$9 \times 4\frac{1}{2} \times 2\frac{1}{2} - \frac{5}{8}$	
Feather edge	$9 \times 4\frac{1}{2} \times 2\frac{1}{2} - \frac{1}{8}$	
No. 1 Jamb	$9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ (rounded corner).	
No. 2 Jamb	$9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ (rounded corner and beveled corner).	
No. 3 Jamb	$9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ (rounded corner).	
No. 3 Bullhead	$9 \times 4\frac{1}{2} \times 3 - 2$ (see illustration).	
Checker	$9 \times 3 \times 3$ or $9 \times 2\frac{3}{4} \times 2\frac{3}{4}$ .	
Large 9 in.		
No. 1 Wedge	$9 \times 6\frac{3}{4} \times 1\frac{7}{8}$ : 5 ft. diam. inside. 102 brick to the circle.	
Large 9-in.		
No. 2 Wedge	$9 \times 6\frac{3}{4} \times 2\frac{1}{2} - 1\frac{1}{2}$ : 2 ft. 6 in. diam. inside. 63 brick to the circle.	
Edge arch	$9 \times 4\frac{1}{2} - 3 \times 2\frac{1}{2}$ .	
Checker tile	$18$ (or $20$ or $24$ ) $\times 6 \times 3$ .	
Checker tile (mill tile)	$18$ (or $20$ or $24$ ) $\times 9 \times 3$ .	

<sup>1</sup> As made by the Stowe-Fuller Co., Cleveland, Ohio. Other makers deviate slightly from the figures given for keys.<sup>2</sup> The wedge brick taper from end to end, as do the keys, No. 3 neck, and bullhead.



TABLE OF FIREBRICK FOR VARIOUS CIRCLES<sup>1</sup>

Inside diameter of circle	Arch bricks		Total	9-in. key bricks					Wedge bricks			134-in. key bricks			Total	
	No. 2 arch	No. 1 arch		9 in.	No. 4 key	No. 3 key	No. 2 key	No. 1 key	9-in.	No. 2 wedge	No. 1 wedge	9-in.	No. 2 wedge	No. 1 wedge		Straights
Ft. In																
1 6	42		42	25	13					25	60					60
2 0	10	40	50	17	25					30	48					68
2 6		57	57		38					38	36	20				76
3 0		57	57		32					42	24	40				83
3 6		57	64		25	10				46	12	59				91
4 0		57	72		25	21				51		83				98
4 6		57	79		19	32				55		98				106
5 0		57	86		13	42				59		98				113
5 6		57	94		6	53				63		98				121
6 0		57	101			63				67		98				128
6 6		57	109			58				71		98				136
7 0		57	116			52				76		98				144
7 6		57	124			47				80		98				151
8 0		57	131			42				84		98				159
8 6		57	139			37				88		98				166
9 0		57	146			31				92		98				174
9 6		57	154			26				97		98				181
10 0		57	161			21				101		98				189
10 6		57	169			16				105		98				196
11 0		57	176			11				109		98				204
11 6		57	184			5				113		98				211
12 0		57	191							117		98				218
12 6		57	199							122		98				225
13 0		57								126		98				232
13 6		57								130		98				239
14 0		57								134		98				246
14 6		57								139		98				253
15 0		57								147		98				260
16 0		57										98				268

<sup>1</sup> From the Stowe-Fuller Co.'s catalog.

### Hints on Brick Laying

One ton of fire-clay ought to lay about 6000 brick. The composition in which they are laid should be, if possible, of the same composition as the brick themselves, and the brick should be dipped in a thin paste and laid, not laid in a mortar. In general, the thinner the bond between the bricks the better the work. The joints are the zones of greatest weakness and are soonest attacked. For metallurgical furnaces it appears that the denser the brick the less its absorption. Magnesite brick are best laid in a suspension of finely ground magnesite in anhydrous tar, or magnesite and linseed oil, or in a suspension of magnesite in a 20 per cent. sodium silicate solution. Silica brick are best laid in a thin paste of 60 fine sand, 40 fire-clay. About  $\frac{5}{32}$  in. per foot should be left for expansion in a furnace bottom.

### *Always store refractories in a dry place*

Magnesite bricks are good conductors of heat, and where this conductivity would injure the armoring of the furnace, the brick should be backed by asbestos or some other non-conductor. Great variations of temperature, or heating when they are moistened with water or oil, will cause spalling. Magnesite brick should not be subjected to great loads when hot.

For red-brick work 9 cu. ft. of sand and 3 bu. of lime will lay 1000 brick.

### Brickwork Table<sup>1</sup>

- 1 sq. ft. of  $4\frac{1}{2}$ -in. wall requires seven bricks.
- 1 sq. ft. of  $13\frac{1}{2}$ -in. wall requires twenty-one bricks.
- 1 cu. ft. of brickwork requires seventeen 9-in. bricks.
- 1 cu. ft. of fire-clay brickwork weighs 150 lb.
- 1 cu. ft. of silica brickwork weighs 130 lb.
- 1000 bricks (closely stacked) occupy 56 cu. ft.
- 1000 bricks (loosely stacked) occupy 72 cu. ft.

M. S. WOŁODINE has probably done the best work on the thermal properties of the fire brick. A. L. QUENEAU deduces, among others, the following conclusions from WOŁODINE's work:

1. All terra cotta, building bricks and fire bricks have practically equal coefficients of heat conductivity. The coefficients are differentiated in this class of refractory materials solely by the temperature of burning and not by the character of the clays or by their chemical composition.

2. In all refractory materials, including the special bricks, such as chrome, magnesia, carborundum and graphite, the heat conductivity is a direct function of the temperature of burning.

3. The coefficient of heat conductivity of chrome brick is practically independent of the temperature.

4. There are remarkable variations in the permeability to gases of the same bricks with increase in temperature. In one case the permeability changed from 3.3 liters per hour to

<sup>1</sup> HAVARD, "Furnaces and Refractories."

241 liters per hour. This shows the importance of scientifically selecting the clay mixtures for a given work as for crucibles or retorts where, as in zinc metallurgy, the permeability to gases has a material influence on the metal recovery. In this connection the nil permeability of graphite crucibles is to be noted. Perhaps the same results might be obtained at a much reduced cost by substituting clay flakes for the graphite flakes proposed by H. Putz (German pat. 198,840 of Sept. 29, 1907).

5. To secure efficient heat insulation, refractory materials should be burned at the lowest allowable temperature. This burning temperature is generally known; it is the maximum temperature to which the bricks will be exposed in the furnaces. The use of the maximum temperature is necessary in order to prevent the brick from shrinking any further when set in the furnace walls. Though this last fact is well known it is often neglected, and a shortening of the furnace life is the result.

6. The gas permeability of the bricks of blast-furnace linings must have an important bearing on their life, owing to the destructive action of carbon monoxide in contact with the iron oxide present in the brick.

There is no question that the absorption of metals by a furnace bottom will be directly proportional to the air spaces in the original brick; consequently in work with any of the non-ferrous metals, the nearer the ratio of the specific gravity of the brick in bulk to the true specific gravity of the constituent material approaches unity, the better the brick.

### Short Description of the Common Refractories

**Alundum.**—Melting point, 2050°C.; specific heat, 0.195–0.198 at 100°C.; thermal conductivity about twice that of fire brick. Electric resistivity, at 528°C., 130 megohms per cc.; at 730°, 16 megohms; at 892°, 5.3 megohms; at 1020°, 1.8 megohms. Coefficient of expansion, 0.0000071 per deg. C.; maximum crushing strength, 7½ tons per square inch; tensile strength, 1700 lb. per square inch. Specific gravity, 3.91.

**Asbestos.**—A very poor conductor of heat and refractory, but will not stand molten slags. The composition of a typical Canadian asbestos is: MgO, 40.07; FeO, 0.87; Al<sub>2</sub>O<sub>3</sub>, 3.67; SiO<sub>2</sub>, 39.05, H<sub>2</sub>O, 14.48; total 98.14 per cent.

**Bauxite.**—Bauxite melts at 1820°C., but as bauxite shrinks about 30 per cent. and crumbles in calcining, some silica must be added to make a good brick. The washed bauxite is calcined at from 1350° to 1400°, ground, pugged with about 4 per cent. of a highly aluminous plastic clay, balled, dried and calcined. The mixture is then ground, pugged again with clay and hand molded. Basic open-hearth brick should not contain over 12 per cent. of silica. An analysis of an American bauxite brick is: SiO<sub>2</sub>, 2 per cent.; TiO<sub>2</sub>, 5 per cent.; Al<sub>2</sub>O<sub>3</sub>, 90.5 per cent.; Fe<sub>2</sub>O<sub>3</sub>, 1 per cent.; and CaO, 1.5–2 per cent. The crushing strength may be as high as 10,000 lb. per square inch, but in general the bricks are weak.

Calcined,  $\text{SiO}_2$ , 3.66 per cent.;  $\text{Fe}_2\text{O}_3$  and  $\text{Al}_2\text{O}_3$ , 4.80;  $\text{CaO}$ , 55.50;  $\text{MgO}$ , 34.83;  $\text{CO}_2$ , 1.06 per cent.

**Durox.**—A patented refractory of the mullite type made by the Vitrefrac Co.

**Fibrox.**—A fibrous silicon oxycarbide, formed in the presence of certain catalytic agents, of which calcium fluoride is one, by the reaction between vapors of silicon and carbon monoxide or dioxide. It is a soft, resilient, fibrous material. Its apparent weight is about  $2\frac{1}{2}$  to 3 grams per liter, its real specific gravity about 1.84 to 2.2. It is claimed to be the best heat insulator known. It oxidizes slowly above  $1000^\circ\text{C}$ .

**Firefrac.**—A refractory cement made by The Carborundum Co. It will bond about 60 per cent. of its weight of such materials as carborundum firesand, crushed silica or silica sand, and can be used wherever firebrick are used.

**Fused Silica.**—Thermal conductivity high. Melting point,  $1430^\circ\text{C}$ . Sp. gr., 2.5–2.6. Specific heat, 0.776. Coefficient of expansion, 0.00000539 per deg. C.

**Ganister.**—Another classic English refractory. A typical analysis, from HARBORD:  $\text{SiO}_2$ , 94.60 per cent.;  $\text{Al}_2\text{O}_3$ , 1.40;  $\text{Fe}_2\text{O}_3$ , 0.90;  $\text{CaO}$ , 0.48;  $\text{MgO}$ , 0.16; alkalis, 0.14; water, 2.60 per cent.

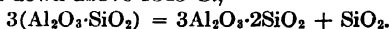
**Hytempite.**—A proprietary furnace bonding material made by the Quigley Furnace Specialties Co. Retains its strength up to about  $3100^\circ\text{F}$ .

**Infrac.**—An insulating refractory made by The Carborundum Co. Has about the same conductivity as diatomaceous insulation, begins to shrink at  $2650^\circ\text{F}$ ., and softens above  $3100^\circ\text{F}$ . At  $2600^\circ\text{F}$ . the bricks crush under 43 lb. per sq. in. load.

**Lime.**—FITZGERALD reports that lime fused in the electric furnace may be a very useful refractory. It is a better conductor of heat than ordinary lime. Blocks cut from it resist quick heating followed by sudden cooling. Fused lime resists exposure to moist air remarkably well, hydration being a matter of days.

**Magnesite.**—Composition, Federal brick:  $\text{SiO}_2$ , 1.46 per cent.;  $\text{Al}_2\text{O}_3$ , 1.50;  $\text{Fe}_2\text{O}_3$ , 7.58;  $\text{CaO}$ , 3.14;  $\text{MgO}$ , 86.36 per cent. Conducts heat two to four times as fast as clay brick. Usually laid dry, or in a paste made of magnesite clay and 20 per cent. water-glass solution. Magnesite can only be considered "dead-burned" when the final ignition temperature exceeds  $1800^\circ\text{C}$ . The greatest objection to magnesite is its cracking when heated to a high temperature. This is due to its shrinkage; a piece of magnesite heated to  $350^\circ$  may have a density of 3.19, while electrically fused its density will be 3.65.

**Mullite.**—There are three closely related aluminosilicates of the composition  $\text{Al}_2\text{O}_3\cdot\text{SiO}_2$ : sillimanite, andalusite, and cyanite. Until recently it was thought the two latter were converted to sillimanite on heating, but BOWEN and GREIG (*Journ. Am. Cer. Sec.*, Vol. 7, p. 238) have shown sillimanite itself breaks down above  $1545^\circ\text{C}$ .,



The aluminum silicate formed is known as mullite, and the silica forms a glass with any impurities present, which bonds the mullite together.

## PHYSICAL PROPERTIES

	Crystalline structure	Sp. gr.	Volume change to mullite	Decomp temp.
Andalusite...	Orthorhombic	3.16-3.20	Small	1390°C.
Sillimanite....	Orthorhombic	3.23-3.24	Larger	1530°C.
Cyanite.....	Triclinic	3.56-3.57	Larger	1370°C.
Mullite....	Orthorhombic	3.156	None	1810°C. <sup>1</sup>

<sup>1</sup> Begins to melt.

It is obvious that a mullite brick because of freedom from undesirable expansion changes and its high temperature of incipient fusion has many advantages for high temperature work. The Vitrefrax Company is manufacturing brick that are practically mullite; the Corning Glass Works is casting blocks and shapes from mullite fused in an electric arc furnace.

Mullite has a perfectly definite melting point at 1816°C.

Study of the expansion behavior of mullite, prepared from raw materials of various sources, was made at the Bureau of Standards (*Bull.* 134). These materials were four in number:

A. prepared from andalusite

B. prepared from dumortierite

C. prepared from Indian cyanite

D. prepared by electric fusion of necessary alumina and silica for mullite.

The specimens were approximately 6 × 1 × 1 in. in size and were all subjected to a firing of at least 1400°C. prior to the test.

## RESULTS OF THERMAL EXPANSION TESTS ON MULLITE, 20 TO 1800°C.

Sample	Maximum temp., °C.		Total expansion at 1000° in per cent. of unit length		Contraction commences at, deg.		Maximum expansion temp., °C.		Maximum total expansion in per cent. of unit length	
Run .. . . .	I	II	I	II	I	II	I	II	I	II
A	1,795	1,800	0.510	0.460	None	1,770	1,795	1,770	1.390	0.995
B	1,670	1,730	.495	.495	1,400	1,520	1,400	1,520	.685	.745
C	1,795	1,800	.478	.490	1,370	1,700	1,370	1,700	.603	.842
D	1,765	1,765	.494	.520	1,425	1,600	1,430	1,600	.767	.340

Peculiarities in behavior of the samples are listed below:

**A**—Only specimen to show no contraction, rate of expansion increasing decidedly at 1500°. Composed of sizable mullite crystals and some corundum.

**B**—Nearly uniform expansion rate to 1500°, excepting a sensible increase between 600 and 700°. Contained much glass, with mullite, but no corundum.

**C**—Despite preshrinking at 1400°, shrinking began in first run at 1250°. Second heating caused growth in crystals.

**D**—Petrographic examination after first heating reveals almost pure mullite, with only minute quantities of glass and corundum.

**Refrax.**—A recrystallized carborundum, held in solid form by the interlocking of silicon carbide crystals.

**Silfrax.**—A recrystallized silicon carbide used chiefly for pyrometer protection tubes.

**Silica Sand.**—An analysis of the sand used for furnace bottoms in Swansea is (from PERCY):  $\text{SiO}_2$ , 87.87 per cent.;  $\text{Al}_2\text{O}_3$ , 2.13;  $\text{Fe}_2\text{O}_3$ , 2.72;  $\text{CaO}$ , 3.79;  $\text{MgO}$ , 0.21; volatile, 2.60 per cent. Silica melts at 1750°, after softening at 1500° and becoming glassy at 1700°C. It expands on heating and does not return exactly to its former volume. In general, silica brick are highly refractory, porous, of low specific gravity, brittle and hard to cut, poor conductors of heat, inelastic, and not resistant to sudden changes of temperature. The compressive strength is about 1900 to 4000 lb. per square inch. A typical American silica-lime brick analyzed as follows:  $\text{SiO}_2$ , 93.92 per cent.;  $\text{Fe}_2\text{O}_3$ , 0.79;  $\text{Al}_2\text{O}_3$ , 3.07;  $\text{CaO}$ , 2.55;  $\text{MgO}$ , 0.18; porosity, 18.58 per cent. of volume, expansion, 0.188 in. per foot. Another brick gave 0.346 in. per foot expansion.

#### ALLOTROPIC FORMS OF SILICA

	Density	Temp. of transformation, °C.
Quartz . . . . .	2 65	570
Cristobalite . . . . .	2 34	225
Tridymite . . . . .	2 27	150
Chalcedony . . . . .	2 58	570
Glass . . . . .	2 22	

The transformation is quartz  $\rightarrow$  cristobalite  $\rightarrow$  tridymite.

**Siloxicon.**—A more or less oxidized carborundum, the amorphous crystallon of the Norton Co.

**Vitreosil.**—Commercial fused silica. Rather to be considered as a non-corrodible material than a refractory. Softens at 1100°C. Thermal expansion, 0.00000054 per deg. C. Hardness, Moh's scale, 7. Sp. gr. 2.07 (non-transparent); 2.22 transparent.

**Zirconia.**—A pure white refractory<sup>a</sup> of a density of about 5.9 and a melting point of about 2950°C. Its first important use was to replace the calcium-oxide cylinders in the DRUMMOND light. Used also in the first WELSBACH experiments. Its heat-conducting power is not over half that of firebrick. Has been used as a lining of a SIEMENS-MARTIN furnace with good results. Owing to its thermal conductivity a 2-in. lining of zirconia is equal to 4 in. of chamotte. It is practically unaffected except by molten fluorides and bisilicates.

All binding materials tend to lower the melting point of zirconia. In lining furnaces or other metallurgical apparatus, natural zirconia can be mixed with anhydrous tar as a binder, in which case wooden forms are generally used. These are allowed to remain in place and consumed during the initial heat. The temperature should be raised slowly at first, while burning out the tar, after which a temperature of at least 1400°C. must be maintained for about 48 hr. Natural zirconia begins to fuse at about 1800°C., and at about 2000°C. there is a noticeable volatilization of silica and other impurities.

In the manufacture of natural zirconia brick, muffles, crucibles, etc., about 2 per cent. of air-slacked lime as a binder has been used with success. In former practice, a batch composed of 75 per cent. 100-mesh zirconia, 23 per cent. of 10 mesh, and 2 per cent. of slacked lime, is worked into a plastic with a 3 per cent. solution of 38°Bé. sodium silicate. The bricks or ware are then pressed from this and allowed to thoroughly dry in a warm atmosphere. The procedure from this point on is the same as in the burning of ordinary refractories, except that a temperature of at least 1400°C. is necessary to secure the proper vitrification.

### MELTING POINTS OF FIRE BRICK

Alumina	2100°(c), softens 1920°C.
Alundum	2050°C.(a)
Bauxite	1820°C.(b)
Bauxite brick	1620-1785°C.(a)
Bone-ash cupel	1865°C.(c)
Carborundum	Decomposes at 2220° with fusing.(b)
Chromite	2050°C.(a); 2180°(b); 1545°-1730°.(c)
Clay brick, 1st class	1555-1740°C.
Clay brick, 2nd class	1400-1650°C.
Diatom nonpareil brick	900°C.(d)
Dinas silica	1680°C.(c)
Kaolinite (pure)	1740°C.(b) 1830°.
Lime (CaO)	Softens about 2040°C.
Magnesia	2720°C.(a), softens about 2500°C.
Magnesite brick	2165°C.(a), softens about 2080°C.
Silica	1700-1705°C.
Silicon carbide	2700° + C.

(a) According to Bureau of Standards. Dissociates at 2250°C.

(b) *Bull. Tech. A. et M.*, July, 1913, p. 728.

(c) W. H. PATTERSON, "Brit. Iron and Steel Inst. Carnegie Scholarship Memoirs," No. 6, p. 231, 1914.

(d) Information from manufacturers. An insulator, not a refractory.

As the density of zirconia is rather high (about 5.9), it has been suggested where imperviousness is not desired, that the incorporation of certain organic substances or volatile salts which would be destroyed during firing, thus producing small air cells, might serve to lighten the finished product without impairing its efficiency. Sawdust, cork dust or certain ammonium salts might prove of value for such aëration.

Using pure zirconium oxide with 3 to 10 per cent. of magnesia, and using starch, phosphoric acid, glycerin or borates as binders very remarkable heat-resisting ware can be manufactured. The forms are dried for several days at a low temperature and then fired in the electric furnace at 2000–2300°C. Owing to the low coefficient of expansion this ware can be plunged red-hot into water without cracking.

Up to 1800°C., zirconia probably has the lowest thermal conductivity of any commercially available refractory. A 2-in. lining of zirconia is equal to 4 in. of chamotte.

Zirconia does not react with silica even when heated to 3000°C., the silica merely melts and runs into its pores. When heated in contact with carbon it forms a carbide. Molten fluorides and bisilicates affect zirconia.

**Zirconia-Chromium Oxide.**—In the range 2000–2500°C., refractories of these oxides are probably the most satisfactory available.

**Zirconia-Thoria.**—G. A. MERRITT of the Bureau of Standards developed a refractory of equi-molecular parts of zirconia and thoria, melting at 3000°C. Where price is no object, the mixture is interesting.

**Zirconium Silicate.**—This material apparently has an even lower coefficient of thermal expansion than has fused quartz. It also has high electrical resistance even at bright red heat.

**Testing Refractory Materials under Load.**—The melting point of various clays used in the manufacture of firebrick and retort material was found to be 200°–320°C. lower when the clay was under pressures of 54 to 112 lb. per square inch.

It should be remembered that it also often occurs that a very refractory material, as tested alongside SEGER cones, will not stand up under a load. Thus, China clay tested by Dr. MELLOR yields at 1410°C., but does not fuse until 1770°C., while fireclay bricks yielding under equal loads at 1435°C. fused at 1710°, and siliceous brick yielding at 1580°C., melted at 1750°C. In general the higher the silica content the greater the temperature resisted.

The following procedure is recommended in tentative tests submitted by the Committee on Refractories of the American Society for Testing Materials. A full-sized brick on end is heated under load under specified conditions and the resulting deformation measured. A furnace is described. It is heated by two tangentially disposed burners—gas or oil—the flames from which are separated from the brick by a cylinder of alundum. The brick should be uniformly heated and its temperature measured by a thermo-couple, the junction of which is 1 in.



from a face of the brick. Alternatively an optical pyrometer may be used. The brick rests on a highly refractory block, e.g., of carborundum, placed at the center of the furnace, and carries another block of the same material which projects through the top of the furnace. The load is applied to this block by means of a cross beam, supported on guide pillars and carrying weights attached at each end so as to apply a pressure on the brick of 25 lb. per sq. in. The specimen is heated to the test temperature in  $4\frac{1}{2}$  hours and maintained there for  $1\frac{1}{2}$  hours. Silica material is tested at  $1500^{\circ}\text{C}.$ , high-grade clay good at  $1350^{\circ}\text{C}.$ , medium at  $1300^{\circ}\text{C}.$ , and low-grade at  $1100^{\circ}\text{C}.$  The cooling is slow and lasts 5 hours at least. The length of the brick is measured to 0.02 inch before and after test.

**Slag Penetration.**—Tests involving the total immersion of a brick in a bath of molten slag did not give uniform results, besides requiring large and elaborate apparatus. The best results were obtained by studying the absorption of liquid slag in a pocket drilled into one face of the brick. The drill was pointed at an angle of  $150^{\circ}$ , and cut a hole  $2\frac{1}{2}$  in. in diameter, the depth at the side being  $\frac{1}{2}$  in. The hole was cleaned out, and the brick then heated to  $1350^{\circ}\text{C}.$  A known quantity of powdered slag was placed in the pocket, and after maintaining a temperature of  $1350^{\circ}\text{C}.$  for 2 hours, the brick was allowed to cool. When cold it was sawn in two, so as to bisect the original cavity at the center, thus exposing an area of penetration of the slag. This area was measured by means of a planimeter. Increasing the duration of the test above 2 hours had no great effect, neither had the fineness of the slag, although it was usually ground to pass a 40-mesh sieve. Increasing the quantity of slag taken did not markedly affect the area of penetration if corrected for the differing area of contact.

**Crushing Test.**—The brick to be tested is ground so that opposite faces are parallel, measured, and heated in a furnace to  $1350^{\circ}\text{C}.$  The time taken to heat up should be at least 6 hours, and the temperature of  $1350^{\circ}\text{C}.$  should be maintained for 2 hours. The brick is then quickly placed in position in a testing machine of standard type, with asbestos board above and below the specimen. The crushing weight is determined.

### Volatilization of Oxides

According to W. R. MOTT in *Journ. Am. Electrochem. Soc.*, 1918, Vol. 34, oxides volatilize in the following order:  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{Li}_2\text{O}$ ,  $\text{V}_2\text{O}_5$ ,  $\text{B}_2\text{O}_3$ ,  $\text{BaO}$ ,  $\text{SrO}$ ,  $\text{MnO}$ ,  $\text{FeO}$ ,  $\text{CoO}$ ,  $\text{NiO}$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{V}_2\text{O}_4$ ,  $\text{SiO}_2$ , at  $3500^{\circ}\text{C}.$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$  at  $3700^{\circ}\text{C}.$ ,  $\text{Ti}_2\text{O}_3$ ,  $\text{V}_2\text{O}_3$ ,  $\text{Er}_2\text{O}_3$ ,  $\text{Ce}_2\text{O}_3$ ,  $\text{Nd}_2\text{O}_3$ ,  $\text{La}_2\text{O}_3$  at  $4200^{\circ}\text{C}.$ ,  $\text{BeO}$ ,  $\text{Yt}_2\text{O}_3$  at  $4300^{\circ}$ ,  $\text{ZrO}_2$  at  $4300^{\circ}\text{C}.$ ,  $\text{ThO}_2$  at  $4400^{\circ}\text{C}.$

**Resistance to Spalling.**—M. L. HARTMANN and O. A. HONGEN tested the resistance of certain refractories to spalling on being cooled by an air blast after being heated up to  $1350^{\circ}\text{C}.$  The results are as follows<sup>1</sup>:

<sup>1</sup> *Trans. Am. Electro. Chem. Soc.*, 1920.

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	Per cent.	
Bonded carborundum (Carbofrax C).....	0.3	at end of 10th cooling
Bonded carborundum (Carbofrax A)....	6	at end of 10th cooling
Bonded carborundum (Carbofrax B).....	8	at end of 10th cooling
Grade A fireclay.....	9	at end of 10th cooling
Recrystallized carborundum (Refrax).....	12	at end of 10th cooling
Bauxite.....	43	at end of 10th cooling
Zirconia (natural) 80% ZrO <sub>2</sub> .....	53	at end of 10th cooling
Grade B fireclay apparent density 2.04.....	65	at end of 10th cooling
Grade C fireclay apparent density 2.09.....	90	at end of 10th cooling
Chrome.....	100	at end of 7th cooling
Silica.....	100	at end of 4th cooling
Magnesia.....	100	at end of 3rd cooling

## CEMENTS FOR BONDING BRICKS

Kind of Bond	No. 1 Brick	No. 2 Brick	No. 2 Fire brick and tile	No. 3 Brick to lead	No. 4 Brick	No. 6 Brick
Composition of cement	Duro cement	M. A. Knight acid-proof cement	Hytem-pite	Silicate of soda and silic	Dura-Stix	Calcined magnesite
How made	Proprietary mixed with sodium silicate to consistency of cream	Proprietary mixed with sodium silicate to consistency of cream	Proprietary		Proprietary	Mixed with water to creamy consistency
How applied	Bricks are heated to about 150 deg F and laid with a thin joint	Bricks are heated to about 150 deg F and laid with a thin joint	Trowel		Mixed with sand as a paste	Bricks heated and laid with a thin joint
Application	Acids	Acids		Sulphuric acid		For fused and hot alkalies
Suitable range of temperature	0 to 300° F.	0 to 300° F.	To fusion point of brick		Range met in boiler settings	To fusion point of brick

In general, coarse-grained bricks and bricks of high porosity show least spalling losses.

Without exception, all bricks show some checking when subjected to sudden cooling. These check lines are always visible during the first cooling, subsequent coolings render these checkings more visible and usually they develop into cracks and spallings. In the case of carborundum bricks checking is usually visible only when hot.

All bricks lose their sound, metallic ring after quenching or air-cooling.

**Brick for Rotary Cement Kilns.**—While it might be supposed a basic brick would give the best results in cement kilns, according to W. HAMILTON PATTERSON (British Iron & Steel Institute Carnegie Scholarship Memoirs, Vol. 6, 1914) an exceedingly satisfactory brick was:  $\text{SiO}_2$ , 73.2 per cent.;  $\text{Al}_2\text{O}_3$ , 18.3 per cent.;  $\text{Fe}_2\text{O}_3$ , 6.5;  $\text{TiO}_2$ , 0.4 per cent.;  $\text{CaO}$ , 0.4 per cent.;  $\text{MgO}$ , tr; alkalis, 0.50 per cent.; loss on ignition, 0.22 per cent. The melting point was  $1735^\circ\text{C}$ . His explanation of the success of such a brick is that it fuses on the surface and forms with a cement clinker a protective coating. The question of protective coatings may thus be an important one in judging firebrick.

**Brick for Gas Retorts.**—According to F. J. BYWATER (*Journ. Gas Lighting*, 1914, p. 899) silica retorts have recently been used in America with satisfactory results. The retorts were made from crushed ganister quartz (95 per cent.  $\text{SiO}_2$ ), with 2 per cent. milk of lime as binding medium. They were of D-section, and were built up from bricks and tiles. The expansion on heating was  $\frac{1}{8}$  to  $\frac{3}{16}$  in. per foot, and was allowed for by making the joints either with thick paper or strawboard, which burned away leaving a thin carbon joint, or with cement consisting of mild aluminous clay, which shrank when heated. The mouthpiece ends of the retorts were made of solid moulded fireclay so as not to crack when cooled by the opening of the lid.

CRUSHING STRENGTH OF BRICKS AT DIFFERENT TEMPERATURES<sup>1</sup>  
(Pressures in Kilograms per Sq. Cm.; Temperatures in  $^\circ\text{C}$ )

	15°	500°	1000°	1300°	1400°	1500°	1600°
Silica (Star brand)	170	150	120	75	60	48	30
Kaolin . . . .	190	180	210	90	(12)	(1)	0 5
Euboean magnesite	420	380	320	270	240	(185)	(8)
Styrian magnesite	145	130	85	66	(5)	(3)	(1)

Complete Viscosity.—Silica brick . . . . .  $1700^\circ\text{C}$ .  
 Euboean magnesite . . . . .  $1500^\circ\text{C}$ .  
 Styrian magnesite . . . . .  $1300^\circ\text{C}$ .  
 Kaolin brick . . . . .  $1300^\circ\text{C}$ .  
 Ordinary refractory brick . . . .  $1200^\circ\text{C}$ .

<sup>1</sup> H. LE CHATELIER and B. BOGITCH (*Bull. A. I. M. E.*, September, 1918).

The retorts were used with various types of hydraulic discharging machines. In some cases less carbon was formed on the inside of the silica retorts and the surface became glazed, facilitating discharge by pushers. The life of the retorts was  $3\frac{1}{2}$  to 4 years. The thermal conductivity was greater than with clay retorts, the fuel consumption was less, and the output greater owing to the shorter period required for burning off the charge.

HEAT CONDUCTIVITIES OF REFRACTORIES<sup>1</sup>

Specimen	Chem. analysis		Thickness	Apparent sp. gr.	True sp. gr.	Temp. range of measurement		Mean $k$	Remarks
						Lower surface, deg.	Upper surface, deg.		
Fire-clay brick (Farnley).	SiO <sub>2</sub>	60.0	1½"	1.95	2.54	825	260	0.0029	Hard fired to Seger cone 10—11 approximately. } Another specimen.
	Al <sub>2</sub> O <sub>3</sub>	31.0	.....	.....	.....	970	300	0.0029	
	Fe <sub>2</sub> O <sub>3</sub>	1.2	.....	.....	.....	1080	330	0.0036	
	CaO	0.3	.....	.....	.....	1440	550	0.0040	
	MgO	0.9	1½"	.....	.....	1100	420	0.0033	
	Alk.	1.0	.....	.....	.....	1350	510	0.0039	
Fire-clay brick (Farnley).	As above		1½"	1.90	2.67	1005	.....	0.00165	Soft fired to Seger cone 8—9 approximately.
						1020	.....	0.00120	
Silicious brick (Farnley).	SiO <sub>2</sub>	82.5	3"	1.82	2.53	1300	310	0.0025	With many silica grains.
	Al <sub>2</sub> O <sub>3</sub>	16.1	.....	.....	.....	.....	.....	.....	
	Fe <sub>2</sub> O <sub>3</sub>	1.2	.....	.....	.....	.....	.....	.....	
	CaO & MgO		Tr.	.....	.....	.....	.....	.....	
	Alk.	1.3	.....	.....	.....	.....	.....	.....	
Silica brick (Gregory).	SiO <sub>2</sub>	95.3	2½"	1.75	2.32	1240	440	0.0039	} Another specimen. Both coarse grained.
	Al <sub>2</sub> O <sub>3</sub>	2.0	.....	.....	.....	.....	.....	.....	
	Fe <sub>2</sub> O <sub>3</sub>	1.1	2½"	1.74	2.32	995	295	0.0030	
	CaO	1.5	.....	.....	.....	.....	.....	.....	
						1210	370	0.0035	
"						1395	440	0.0042	
Magnesia brick (Mabor).	SiO <sub>2</sub>	5.0	2½"	2.40	3.51	380	270	0.0170	Finer grained than the above.
	Al <sub>2</sub> O <sub>3</sub>	0.4	.....	.....	.....	560	325	0.0151	
	Fe <sub>2</sub> O <sub>3</sub>	1.6	.....	.....	.....	600	400	0.0148	
	CaO	1.7	.....	.....	.....	700	450	0.0132	
	MgO	92.1	.....	.....	.....	750	470	0.0116	
						875	525	0.0110	
						1025	580	0.0101	
						1040	590	0.0098	
						1370	690	0.0091	

The chemical analysis and porosity data were not derived from measurements on the actual test brick but on similar specimens of the same make. They will correspond approximately with those of the test bricks.

<sup>1</sup> G. DOUGILL, H. J. HODSMAN, and J. W. COBB in *Journ. Soc. Chem. Ind.*, May 15, 1915.

# REFRACTORIES

## MELTING POINTS OF SOME REFRACTORY OXIDES

Oxide	Temperature of volatilization	Melting point	Color of melt and sublimate	Furnace used	Remarks
BeO	.....	About 2400°	White like porcelain	Cathode ray	Evaporated just before melting.
MgO	.....	2800° <sup>(a)</sup>	.....	Both furnaces	Dissociated into its elements.
CaO	About 3600°	2572° <sup>(a)</sup>	.....	Cathode ray	Tendency for melt to crystallize.
Al <sub>2</sub> O <sub>3</sub>	3690°	2050°	Colorless, glassy	Cathode ray	Dissociated, forming lower oxide.
La <sub>2</sub> O <sub>3</sub>	3750°	About 2000°	Clear yellow melt	Cathode ray	Evaporated just before melting
ZrO <sub>2</sub>	4200°	2563°	White opaque melt	Cathode ray	and dissociated into its elements.
	4300°				Dissociated, forming lower oxide.
SnO <sub>2</sub>	.....	Did not melt	.....	Cathode ray	
SnO	Red heat	Did not melt	Black sublimate	Cathode ray	
CeO <sub>2</sub>	4075°	Did not melt	Transparent sublimate	Cathode ray	
			in crucible		
ThO <sub>2</sub>	About 4400°	2000°	White opaque sublimate	Cathode ray	
VO <sub>2</sub>	Did not evaporate	Did not melt	.....	Cathode ray	Dissociated probably to VO <sub>2</sub>
V <sub>2</sub> O <sub>5</sub>	Red heat	Did not melt	Blue-black sublimate	Cathode ray	
Ta <sub>2</sub> O <sub>5</sub>	Did not evaporate	Did not melt	.....	Cathode ray	
MnO	.....	1650°	Black	Cathode ray	Melt crystallized.

<sup>(a)</sup> According to C. W. KANOUR, *Journ. Franklin Inst.*, p. 587, 1913; other determinations according to TIEDE and BRANDBRUGGE, *Zell. anorg. Chem.*, 1914, p. 129.

CONDUCTIVITY, DENSITY, POROSITY AND PERMEABILITY OF REFRACTORY MATERIALS<sup>1</sup>

Material	Conductivity		Density		Porosity in per cent of volume	Permeability		Tem- perature of burning
	Gram-cal.-sec per sq cm per cm per 1°C. difference	Kg.-cal.-hr. m per 1°C difference	True δ	Appar- ent δ		Cm. <sup>3</sup> sec. per sq. cm. per cm.	Lit.-hr. per sq. in. per m.	
Fire-clay brick	0 0037	1 32	2 61	1 81	30 8	0 0409	14.72	1050
Fire-clay brick	0 0030	1 81	2 05	1 91	24 1	0 069	24 84	1300
Checker brick	0 0039	1 42	2 65	1 91	27 8	0 0465	16 74	1300
Bauxite brick	0 0033	1 19	3 12	1 92	38 4	0 212	76 39	1300
Silica brick	0 0020	0 71	2 75	1 58	42 58	0 0092	3.32	1050
Silica brick	0 0031	1 12	2 62	1 50	42 9	0 0536	192.9	1300
Magnesia brick	0 0045	2 35	3 39	2 00	41 0	0 0097	3.49	1300
Magnesia brick	0 0058	2 08	3 07	2 00	35 1	0 517	186 1	1050
Carborundum brick	0 0033	1 20	3 02	1 96	35 2	0 0053	1.90	1050
Carborundum brick	0 0145	5 22	2 83	1 96	30 6	0 0043	1.55	1300
Chromite (unburned)	0 0057	2 05	4 60	3 19	21 3	0 0568	20.45	1300
Chromite brick (clay binder)	0 0034	1.23	3 38	2 49	26 4	0 0075	1.7	1300
Kieselguhr	0 0018	0 64	2 48	1 03	38 0	0 0057	34 45	1300
Graphite brick	0 024	8.64	2.42	1.79	26.0	0 0	0 0	1400
Porcelain	0 0046	1.66	2.56	1.90	25 7	0 0015	0.53	1050
Building brick	0 0037	1 34	2.60	1 41	45 7	0 0164	5.90	1050
Light clay	0 0024	0 86	2.60	1 41	45 7	0 0164	5.90	1050

In general, the conductivity increases with an increase in the original temperature of burning and the temperature of using. In this connection it should be noted that commercial silica brick are burned at higher temperatures than 1300°C. and probably 200° higher than clay brick. The ordinary American silica brick is therefore probably a better conductor than is the American clay brick and for metallurgical furnace work the above figures are probably extremely misleading. Chromite, however, has a conductivity with practically no temperature coefficient.

<sup>1</sup> F. T. HAVARD, "Refractories and Furnaces"

# HEAT CONDUCTIVITIES OF REFRACTORY MATERIALS<sup>1</sup>

(See also Tables on pp. 561, 562 and 564)

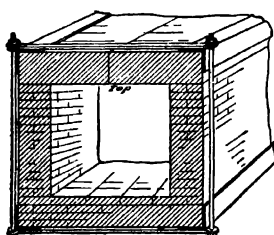
## Heat conductivity

Material	Gr. cal. sec. p. sq. in p. cm. p. 1°C. diff.	Kg. cal. hr. p. sq. m. per m. p. 1°C. diff.	Relative per cent
Graphite brick . . . . .	0.025	9.0	100.0
Carborundum brick . . . . .	0.0231	8.32	92.4
Magnesia brick . . . . .	0.0071	2.54	28.4
Chromite brick . . . . .	0.0057	2.05	22.8
Fire brick . . . . .	0.0042	1.50	16.7
Checker brick . . . . .	0.0039	1.42	15.8
Gas-retort brick . . . . .	0.0038	1.36	15.2
Building brick . . . . .	0.0035	1.26	14.0
Bauxite brick . . . . .	0.0033	1.19	13.2
Glass pot . . . . .	0.0027	0.96	12.4
Terra cotta . . . . .	0.0023	0.84	9.3
Silica brick . . . . .	0.0020	0.71	7.8
Kieselguhr brick . . . . .	0.0018	0.64	7.1

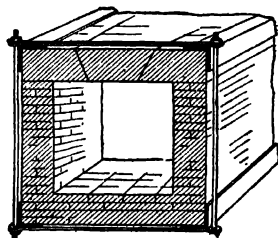
<sup>1</sup> HAVARD, "Furnaces and Refractories," p. 280.

The above are average conductivities only. The conductivity varies with the porosity, permeability, size, character, and number of grains and pores in the brick, the temperature at which the brick was burned and the temperature at which it is used. In general the conductivity is greater the higher the temperature at which the brick is burned. Thus, a clay brick burned at 1050°C. has a conductivity of 1.32, while the same brick burned at 1300°C. has a conductivity of 1.81 (HAVARD). The conductivity also increases with increase of temperature of the experiment.

## Arch Construction<sup>1</sup>



Showing way of covering over a flue on a small furnace without use of an arch. This is practical to spans to as large as 30" to 36". This form of construction is particularly applicable where a flat covering is advantageous.



Showing manner of laying a 'dutch arch,' simple and cheap for spans up to 30" to 40" or even larger. This form of construction is particularly good where flat cover of larger size than the preceding is desired.

<sup>1</sup> *Metallurgical and Chemical Engineering*, November, 1913.

## PHYSICAL PROPERTIES OF REFRACTORY MATERIALS

Apparatus	Specific heat	Thermal conductivity in gram cal. per sec. per cm. <sup>2</sup> per deg. C. Mean value K approximate 0° to 1000°C	Compressive strength in lb. per sq. in.	Spalling loss ten heats to 1350°C. with sudden cooling after each (3)	Abrasion (in) by carborundum wheel 12 in. grit 16 Bond G-5 Grade I 1560 surface ft. per min. Brick end held to wheel at 25 lb pressure 5 min. period (4)	Electrical resistance in ohms per cm. <sup>2</sup> (except where megohms are indicated) (5)		
						20°C.	800°C.	1200°C. 1500°C.
Refrax.....	2 30	.16*	12,500*	12 %	.01	107 ohm	6.5 ohm	2.45ohm 1.62 ohm
Carbofrax A.....	2 45	.18*	.....	6 %	.02	.01	12,550	4,160
Carbofrax B.....	2 52	.18*	14,700*	8 %	.02	.03	835,000	29,500
Carbofrax C.....	2 60	.18*	.....	0.3 %	.01	.01	2.38 meg.	62,000
Silica.....	1.66	.19	2,300*	100 %	.17	4.25	57,600	4,160
Fireclay, first quality.....	1 78	.19	1,030*	9 %	.26	.11	803	63
Fireclay, second quality.....	2 83	.19	.....	65 %	.25	.09	558,000	7,710
Chrome.....	2 84	.17	3,900*	100 %	.07	.27	5 meg.	193,000
Zirconia (natural).....	3 3	.22	4,800*	53 %	.02	.06	109,000	6,100
Magnesia.....	2 27	.22	.....	100 %	.05	12.5		
Bauxite.....	1 91	...	.....	43 %	.02	.04		
Quartzite.....	...	...	.....	...	...	...		

\* Best available values subject to revision. Courtesy, The Carborundum Co. See also pp. 561 and 562.

(1) DUDLEY, *Trans. Am. Electrochem. Soc.* 27, 1915, p. 327.

(2) WOOLGIND, *Electrochem. Met. Ind.*, 1909, 17, 382.

(3) HARTMANN and HOUGH, *Trans. Am. Electrochem. Soc.*, 1920, Vol. 37.

(4) HARTMANN and KOHLER, *Trans. Am. Electrochem. Soc.*, 1920, Vol. 37.

(5) HARTMANN, SULLIVAN and ALLEN, *Trans. Am. Electrochem. Soc.*, 1920, Vol. 38.



## SEGER CONES AND THEIR SOFTENING TEMPERATURES

Estimated softening point (deg. C.)	Cone No.	Molecular composition				
		Na <sub>2</sub> O	PbO	Al <sub>2</sub> O <sub>3</sub>	B <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>
595	022	0.5	0.5	.....	1	2.0
605	021	0.5	0.5	0.1	1	2.2
635	020	0.5	0.5	0.2	1	2.4
645	019	0.5	0.5	0.3	1	2.6
695	018	0.5	0.5	0.4	1	2.8
745	017	0.5	0.5	0.5	1	3.0
765	016	0.5	0.5	0.55	1	3.0
790	015	0.5	0.5	0.6	1	3.2
810	014	0.5	0.5	0.65	1	3.3
840	013	0.5	0.5	0.7	1	3.4
855	012	0.5	0.5	0.75	1	3.5
890	011	0.5	0.5	0.8	1	3.6

## SEGER CONES AND THEIR SOFTENING TEMPERATURES

Estimated softening point (deg. C.)	Cone No.	Molecular composition					
		K <sub>2</sub> O	CaO	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	B <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>
890	010	0.3	0.7	0.2	0.3	0.50	3.50
930	09	0.3	0.7	0.2	0.3	0.45	3.55
945	08	0.3	0.7	0.2	0.3	0.40	3.60
980	07	0.3	0.7	0.2	0.3	0.35	3.65
1010	06	0.3	0.7	0.2	0.3	0.30	3.70
1035	05	0.3	0.7	0.2	0.3	0.25	3.75
1055	04	0.3	0.7	0.2	0.3	0.20	3.80
1090	03	0.3	0.7	0.2	0.3	0.15	3.85
1110	02	0.3	0.7	0.2	0.3	0.10	3.90
1130	01	0.3	0.7	0.2	0.3	0.05	3.95
1140	1	0.3	0.7	0.2	0.3	.....	4.0
1150	2	0.3	0.7	0.1	0.4	.....	4.0
1160	3	0.3	0.7	0.05	0.45	.....	4.0
1175	4	0.3	0.7	.....	0.5	.....	4.0
1190	5	0.3	0.7	.....	0.5	.....	5.0
1210	6	0.3	0.7	.....	0.6	.....	6.0
1230	7	0.3	0.7	.....	0.7	.....	7.0
1245	8	0.3	0.7	.....	0.8	.....	8.0
1265	9	0.3	0.7	.....	0.9	.....	9.0
1285	10	0.3	0.7	.....	1.0	.....	10.0

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## SEGER CONES AND THEIR SOFTENING TEMPERATURES

Estimated softening point (deg. C)	Cone No.	Molecular composition			
		K <sub>2</sub> O	CaO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>
1305	11	0.30	0.70	1 2	12 0
1320	12	0.30	0.70	1.4	14.0
1350	13 <sup>1</sup>	0.30	0.70	1.6	16.0
1395	14	0.30	0.70	1.8	18.0
1420	15	0.30	0.70	2.1	21.0
1450	16	0.30	0.70	2.4	24.0
1465	17	0.30	0.70	2.7	27.0
1490	18	0.30	0.70	3.1	31.0
1515	19	0.30	0.70	3.5	35.0
1525	20	0.30	0.70	3.9	39.0
1 <sup>1</sup> {	21	0.30	0.70	4.4	44.0
	22	0.30	0.70	4.9	49.0
1580	23	0.30	0.70	5.4	54.0
1 <sup>1</sup> {	24	0.30	0.70	6.0	60.0
	25	0.30	0.70	6.6	66.0
1595	26	0.30	0.70	7.2	72.0
1605	27	0.30	0.70	20 0	200 0
1615	28			1	10 0
1 <sup>1</sup>	28 <sup>1</sup> / <sub>2</sub>			1	9 0
1640	29			1	8.0
1 <sup>1</sup>	29 <sup>1</sup> / <sub>2</sub>			1	7.0
1650	30			1	6.0
1680	31			1	5.0
1700	32 <sup>2</sup>			1	4.0
1745	33			1	3.0
1760	34			1	2.5
1770	35			1	2.0
1810	36			1	1.5
1830	37				
1850	38				
1865	39				
1885	40				
1970	41				
2015	42			1	0

<sup>1</sup> These cones are not manufactured, as their estimated softening points lie too close to neighboring cones, and are somewhat irregular.

<sup>2</sup> Pure silica behaves like cone 32.

## METALLIC SALTS AS FUSION PYROMETERS

Salt	Melting point, deg. C.	Salt	Melting point, deg. C.
Na <sub>2</sub> SiO <sub>3</sub>	1088	KBr	730
KeSO <sub>4</sub>	1067	KI	773
BaCl <sub>2</sub>	847	5 KCl + 4 2NaCl	655
K <sub>2</sub> SiO <sub>3</sub>	976	3NaCl + 7KBr	625
Na <sub>2</sub> SO <sub>4</sub>	884	Ba(NO <sub>3</sub> ) <sub>2</sub>	592
5K <sub>2</sub> SO <sub>4</sub> + 5Na <sub>2</sub> SO <sub>4</sub>	850	5KCl + 5K <sub>2</sub> CO <sub>3</sub>	580
3K <sub>2</sub> SO <sub>4</sub> + 7Na <sub>2</sub> SO <sub>4</sub>	830	3Na <sub>2</sub> CO <sub>3</sub> + 3K <sub>2</sub> CO <sub>3</sub> + 2NaCl	
2K <sub>2</sub> SO <sub>4</sub> + 8Na <sub>2</sub> SO <sub>4</sub>	825	+ 2KCl	560
Na <sub>2</sub> CO <sub>3</sub>	851	Ca(NO <sub>3</sub> ) <sub>2</sub>	550
NaCl	804	3K <sub>2</sub> SO <sub>4</sub> + 3Na <sub>2</sub> SO <sub>4</sub> + 2NaCl	
KCl	790	+ 2KCl	520
		NaOH	318
		NaNO <sub>3</sub>	308

ERHARD AND SCHERTEL FUSION PYROMETERS<sup>1</sup>

Composition	Melting point, deg. C.	Composition	Melting point, deg. C.
100 Ag	961	60Au 40Pt	1320
80Ag 20Au	975	55Au 45Pt	1350
60Ag 40Au	995	50Au 50Pt	1385
40Ag 60Au	1020	45Au 55Pt	1420
20Ag 80Au	1045	40Au 60Pt	1460
100Au	1063	35Au 65Pt	1495
95Au 5Pt	1100	30Au 70Pt	1535
90Au 10Pt	1130	25Au 75Pt	1570
85Au 15Pt	1160	20Au 80Pt	1610
80Au 20Pt	1190	15Au 85Pt	1650
75Au 25Pt	1220	10Au 90Pt	1690
70Au 30Pt	1255	5Au 95Pt	1730
65Au 35Pt	1285	100Pt	1755

COLOR SCALES<sup>1</sup>

White and Taylor		Pouillet		Howe	
Name of color	Deg. C.	Name of color	Deg. C.	Name of color	Deg. C.
.....	.....	.....	.....	Lowest visible red in dark.....	470
.....	.....	Incipient redness.....	525	Lowest visible red in daylight.....	475
Dark red.....	566	Dark red.....	700	} Dull red.....	550-
Dark cherry red....	635	Incipient cherry red.....	800		625
Cherry, full red....	740	Cherry red.....	900	Full cherry.....	700
Light cherry, bright	843	Light cherry red.	1000	Light red.....	850
cherry, light red...	899	Dark orange....	1100	.....	.....
Orange.....	941	Light orange....	1200	.....	.....
Light orange.....	996	.....	.....	Full yellow .....	950-
Yellow.....	.....	.....	.....	.....	1000
White.....	1205	White.....	1300	White .....	1150
.....	.....	Brilliant white..	1400	.....	.....
.....	.....	Dazzling white..	1500-	.....	.....
			1600		

<sup>1</sup> HOFMAN, "General Metallurgy," p. 138.

## LOSS OF HEAT BY RADIATION

(Loss in Gram-calories per Square Centimeter of Surface at 100°C. to Surrounding Bodies at 0°C.—PECLET's Figures)

Polished brass.....	0.00108	Russia sheet iron..	0.01410
Copper.....	0.00068	New cast iron....	0.01332
Polished sheet iron..	0.00189	Oxidized iron.....	0.01410
Leaded sheet iron....	0.00273	Glass.....	0.01222
Ordinary sheet iron..	0.01164	Building stone....	0.01500

To correct the above figures for various other ranges of temperature than from 100°C to 0°C., multiply by the factors below.

100°-0°	1.0	600°-0°	26.0
150°-0°	2.0	700°-0°	35.0
200°-0°	3.3	800°-0°	45.3
300°-0°	7.0	900°-0°	57.0
400°-0°	12.0	1000°-0°	70.0
500°-0°	18.3		

In general, radiation from hot bodies to cold surroundings will vary as the difference of the fourth powers of the absolute temperatures.

Heat Emissivity of Various Surfaces<sup>1</sup>

Black body.....	1.00
Copper, oxidized.....	0.72
Copper, calorized.....	0.26
Silver.....	0.03
Cast iron, bright.....	0.22
Cast iron, oxidized.....	0.62
Cast iron, aluminum painted.....	0.50
Cast iron, gold enamelled.....	0.37
Monel metal, bright.....	0.43
Monel metal, oxidized.....	0.43
Brick surfaces (probably).....	0.60-0.75

DIFFUSIVITY<sup>1</sup>

Aluminum....	Air.....	0.18
Antimony....	Cotton..	0.0009
Cadmium.....	Cork.....	0.0001
Copper.....	Ebonite.....	0.0001
Bismuth.....	Rock material (granite,	
Gold.....	etc.).....	0.012
Iron.....	Ice.....	0.011
Lead.....	Concrete.....	0.006
Magnesium....	Average damp soil....	0.0049
Mercury.....	Water.....	0.0014
Nickel.....	Fire brick.....	0.0067
Platinum.....	Building brick..	0.005
Silver.....	Silica.....	0.003
Cast steel....	Silica brick.....	0.0053-0.0098
Tin.....	Magnesia.....	0.0126-0.0226
Zinc.....		

<sup>1</sup> The property of diffusing and transmitting heat is dependent on the conductivity, the density and the specific heat of the body. Thus the coefficient of diffusivity,  $D = \frac{K}{WS_1}$  where  $K$  is the thermal conductivity in gram-calorie-seconds per cm.<sup>2</sup> per 1°C. F. T. HAVARD, "Refractories and Furnaces."

<sup>1</sup> BOYD DUDLEY, JR., "Penn. State Min. Quart.," April, 1915.

## SECTION IX

# MECHANICAL ENGINEERING AND CONSTRUCTION

### CAPACITY OF BELT CONVEYORS<sup>1</sup>

BY R. W. DULL

*Chief Engineer, Stephens-Adamson Mfg. Co.*

The capacity of belt conveyors is a subject upon which various engineers differ materially in results they have published. We suspect that most of the matter published is purely theoretical and not based on actual performance.

There are several conditions which influence the capacity rating; the main one, and the one we will first discuss, is the manner of feeding the conveyor. If the conveyor is fed with a feeder, the maximum capacity is possible, but if the feed is intermittent, the capacity will, of course, be proportionately less. It is usually an advantage to put in a feeding device of some kind if the feed is irregular, as it is often possible to cut down the size of the conveyor, which difference in cost will more than pay for the cost of the feeding device, as well as cut down the size of the driving connections. Uniform loading of the belt also makes the operation of the conveyor less troublesome and usually is desirable in the different processes throughout a plant.

I have made a chart, which is based on good feeding conditions, as we must have some basis from which to start. This chart has curves for various kinds of material, based on the belt speed which I recommend that they should run for the particular kind of material. This speed is given in the curves. If good feeding conditions are not obtainable, allowance must be made on the chart. This is a condition which varies so much we cannot set down any rigid rule, but must leave it to the judgment of the user of the chart to make proper allowance. Variation as great as 50 per cent. is likely and certainly many where 75 per cent. of chart rating is advisable.

Materials undoubtedly will be handled which are not given in the chart, but as a similar substance can be selected, the chart can still be used.

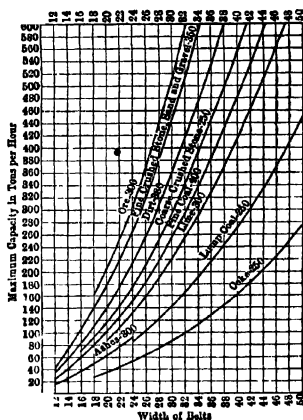
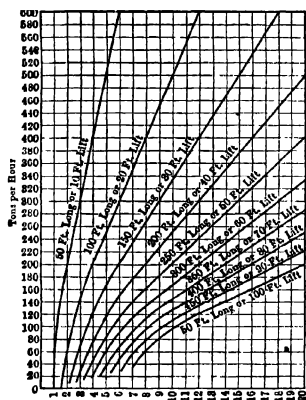
The speed of the belts carrying various substances has been studied carefully to suit all conditions, as for instance, lump

<sup>1</sup> *The Chemical Engineer*, Vol. X, No. 2.

coal and coke, if carried too fast, will be broken up too much to suit the market; and again, very fine material, if carried too fast, will make the mill too dusty.

Some of the curves are stopped off at a certain size belt, as with large pieces, it is not advisable to use a conveyor any narrower regardless of what capacity is required.

Material with large lumps, on an inclined conveyor, will be apt to roll back some, so the capacity allowance should be liberal, and the speed should be reduced slightly, if the conveyor is carrying material down an incline, as the motion of the belt will start the lumps rolling down. These lumps may possibly jump out of the trough of the belt.



Conveyors going up an incline and fed uniformly, can usually go up an angle whose tangent is greater than the coefficient of friction of material on the belt, because the material forms a back stop all the way up the incline. But if the feed is intermittent, the material is apt to get started down the incline and the motion of the belt will have no influence on the motion of the material.

Conveyors should be fed so that the material is delivered in the direction of motion of the belt and with the same velocity as the belt is moving, if possible. The writer has devised a spout to accomplish this purpose and adjustment is possible to suit various kinds of material and different belt speeds. The spout is also made with a bar screen bottom which lets the fine material through onto the belt first which makes a cushion on which the larger lumps fall and saves a great deal of wear on

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the belt. It is not advisable to make small conveyors, such as 12-in. belts, too long, for the material will shift some and lose off before it reaches the end of the conveyor, and liberal allowance in capacity should be made if such a conveyor is installed.

The problem of belt conveyor capacity should be studied carefully and the allowances should be liberal. There have been very many disappointments in results caused by a too hasty decision or too great a desire to keep the first cost down.

Most firms are willing to help the purchaser, and it is usually a good plan to take up the matter of capacity with the manufacturer. It is not always easy for the manufacturer to find out all the conditions within so short an interval of time as he usually has at his disposal, and unless the manufacturer has had considerable experience with this type of conveyor, the purchaser may be led to install apparatus which gives him very disappointing results.

CAPACITY OF BELT CONVEYORS IN TONS OF COAL PER HOUR<sup>1</sup>

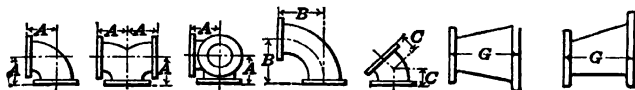
Width of belt, inches	Velocity of belt, feet per minute						
	300	350	400	450	500	550	600
12	27.0	31.5	36	40.5	45.0	49.5	54.0
14	36.7	42.8	49	55.2	61.3	67.4	73.6
16	48.0	56.0	64	72.0	80.0	88.0	96.0
18	60.7	70.8	81	91.2	101.0	111.0	135.0
20	75.0	87.5	100	112.5	125.0	137.5	150.0
24	108.0	126.0	144	162.0	180.0	198.0	216.0
30	168.7	197.0	225	253.0	281.0	307.0	338.0
36	243.0	283.0	324	365.0	405.0	446.0	386.0

<sup>1</sup> KENT's "Mechanical Engineers' Pocketbook."

For materials other than coal, the figures in the above table should be multiplied by the following coefficients.

Material	Coefficient	Material	Coefficient
Ashes damp.....	0.86	Earth.....	1.4
Cement.....	1.76	Sand.....	1.8
Clay.....	1.26	Crushed stone...	2.0
Coke.....	0.60		



THE NEW AMERICAN STANDARD FOR FLANGES AND  
FLANGED FITTINGS

STANDARD

Size	A-A-Face to face, tees and crosses	A-Center to face, ells, tees, and crosses	B-Center to face, long radius ells	C-Center to face 45° ells	D-Face to face laterals	E-Center to face laterals	F-Center to face laterals	G-Face to face reducers	Diameter of flanges	Thickness of flanges	Minimum metal thickness of body
1	7	3½	5	1¾	7½	5¾	1¾	...	4¼	7/16	3/16
1½	7½	3¾	5½	2	8	6¼	1¾	...	4½	7/16	3/16
2	8	4	6	2½	9	7	2	...	5	9/16	3/16
2½	9	4½	6½	3	10½	8	2½	5	6	5/8	3/16
3	10	5	7	3½	12	9½	3	5½	7	5/8	3/16
3½	11	5½	7¾	3	13	10	3	6	7½	¾	3/16
4	12	6	8½	3½	14½	11½	3	6½	8½	13/16	3/16
4½	13	6½	9	4	15	12	3	7	9	15/16	1/2
5	14	7	9½	4	15½	12½	3	7½	9½	15/16	1/2
6	15	7½	10¾	4½	17	13½	3½	8	10	15/16	1/2
7	16	8	11½	5	18	14½	3½	9	11	1	9/16
8	17	8½	12¾	5½	20½	16½	4	10	12½	13/16	5/8
9	18	9	14	5½	22	17½	4½	11	13½	1½	5/8
10	20	10	15½	6	24	19½	4½	11½	15	1½	11/16
12	22	11	16½	6½	25½	20½	5	12	16	13/16	¾
14	24	12	19	7½	30	24½	5½	14	19	1½	13/16
15	28	14	21½	7½	33	27	6	16	21	1½	7/8
16	29	14½	22¾	8	34½	28½	6	17	22½	1½	7/8
18	30	15	24	8	36½	30	6½	18	23½	17/16	1
20	33	16½	26½	8½	39	32	7	19	25	19/16	11/16
22	36	18	29	9½	43	35	8	20	27½	13/16	1½
24	40	20	31½	10	46	37½	8½	22	29½	13/16	13/16
26	44	22	34	11	49½	40½	9	24	32	17/8	1½
28	46	23	36½	13	53	44	9	26	34½	2	15/16
30	48	24	39	14	56	46½	9½	28	36½	23/16	1½
32	50	25	41½	15	59	49	10	30	38¾	2½	17/16
34	52	26	44	16				32	41¾	2½	1½
36	54	27	46½	17				34	43¾	29/16	19/16
38	56	28	49	18				36	46	2½	1½
40	58	29	51½	19				38	48¾	2½	11/16
42	60	30	54	20				40	50¾	2½	1¾
44	62	31	56½	21				42	53	2½	11/16
46	64	32	59	22				44	55¾	2½	1½
48	66	33	61½	23				46	57¾	21/16	11/16
50	68	34	64	24				48	59¾	29/16	2
52	70	35	66½	25				50	61¾	2¾	21/16
54	74	37	69	26				52	64	2¾	2½
56	78	39	71½	27				54	66¾	3	23/16
58	82	41	74	28				56	68¾	3	21/16
	84	42	76½	29				58	71	3½	2½

# 574 METALLURGISTS AND CHEMISTS' HANDBOOK

## THE NEW AMERICAN STANDARD FOR FLANGES AND FLANGED FITTINGS. *Continued*

### STANDARD

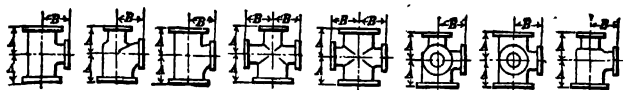
Size	A-A Face to face, tees and crosses	A-Center to face, ell, tees and crosses	B-Center to face, long radius cells	C-Center to face 45° ell	D-Face to face laterals	E-Center to face laterals	F-Center to face laterals	G-Face to face reducers	Diameter of flanges	Thickness of flanges	Minimum metal thickness of body
60	88	44	79	30				60	73	3½	27½
62	90	45	81½	31				62	75¾	3¼	2½
64	94	47	84	32				64	78	3¼	29½
66	96	48	86½	33				66	80	3¾	25½
68	100	50	89	34				68	82¾	3¾	21¼
70	102	51	91½	35				70	84½	3½	23½
72	106	53	94	36				72	86½	3½	21¾
74	108	54	96½	37				74	88½	3½	27½
76	112	56	99	38				76	90¾	3¾	21¾
78	116	58	101½	39				78	93	3¾	3
80	118	59	104	40				80	95¼	3¾	3½
82	120	60	106½	41				82	97½	3¾	3½
84	124	62	109	42				84	99¾	3¾	3½
86	126	63	111½	43				86	102	4	3¼
88	130	65	114	44				88	104¼	4	3½
90	134	67	116½	45				90	106½	4¼	3¾
92	136	68	119	46				92	108¾	4¼	3½
94	138	69	121½	47				94	111	4¼	3¾
96	142	71	124	48				96	113¾	4¼	3¾
98	146	73	126½	49				98	115½	4¾	31¼
100	148	74	129	50				100	117¾	4¾	3¾

The dimensions given above are those adopted as a compromise by the committees responsible for the "U. S. 1912 Standard" and the competing "Manufacturers Standard," and revised by the American Engineering Standards Committee in 1921

## Pipe Fittings

Where screw fittings are required in the pipe lines of chemical plants, it has been found best to use tees in place of elbows and crosses in place of tees. The extra opening in each case is closed by a screw plug. This permits easy cleaning or draining when necessary and also makes it possible to tap into the line without breaking the piping or connections, thus saving both time and expense.

# THE NEW AMERICAN STANDARD FOR FLANGES AND FLANGED FITTINGS. *Continued*



STANDARD

Size	Size of outlet and smaller	AA-Face to face, run	A-Center to face, run	B-Center to face, outlet	Size	Size of outlet and smaller	AA-Face to face, run	A-Center to face, run	B-Center to face, outlet
1					42	28	46	23	30
1 1/4					44	28	46	23	31
1 1/2					46	30	48	24	33
2					48	32	52	26	34
2 1/2					50	32	52	26	35
3	All reducing fittings 1 in to 9 in. inclusive have the same center to face dimensions as straight size fittings				52	34	54	27	36
3 1/2					54	36	58	29	37
4					56	36	58	29	39
4 1/2					58	38	62	31	40
5					60	40	66	33	41
6					62	40	66	33	42
7					64	42	68	34	44
8					66	44	70	35	45
9					68	44	70	35	46
10	6	22	11	11	70	46	74	37	47
12	8	24	12	12	72	48	80	40	48
14	9	28	14	14	74	48	80	40	49
15	9	30	15	15	76	50	84	42	50
16	10	30	15	15	78	52	86	43	52
18	12	26	13	15 1/2	80	52	86	43	53
20	14	28	14	17	82	54	88	44	54
22	15	28	14	18	84	56	94	47	56
24	16	30	15	19	86	56	94	47	57
26	18	32	16	20	88	58	96	48	58
28	18	32	16	21	90	60	100	50	61
30	20	36	18	23	92	60	100	50	62
32	20	36	18	24	94	62	104	52	63
34	22	38	19	25	96	64	106	53	64
36	24	40	20	26	98	64	106	53	65
38	24	40	20	28	100	66	110	55	67
40	26	44	22	29					

The dimensions given above are those adopted as a compromise by the committees responsible for the "U. S. 1912 Standard" and the competing "Manufacturers Standard" and revised by the American Engineering Society Committee in 1921.

# 576 METALLURGISTS AND CHEMISTS' HANDBOOK

## THE NEW AMERICAN STANDARD FOR FLANGES AND FLANGED FITTINGS. *Continued*

### EXTRA HEAVY

Size	Size of outlet and smaller	AA-Face to face, run	A-Center to face, run	B-Center to face, outlet	Size	Size of outlet and smaller	AA-Face to face, run	A-Center to face, run	B-Center to face, outlet
1					16	16	33	16½	16½
1½					18	18	28	14	17
1½					20	14	31	15½	18½
2					22	15	33	16½	20
2½					24	16	34	17	21½
3	All reducing fittings 1 in. to 9 in. inclusive have the same center to face dimensions as straight size fittings.				26	18	38	19	23
3½					28	18	38	19	24
4					30	20	41	20½	25½
4½					32	20	41	20½	26½
5					34	22	44	22	28
6					36	24	47	23½	29½
7					38	24	47	23½	30½
8					40	26	50	25	31½
9					42	28	53	26½	33½
10	10	23	11½	11½	44	28	53	26½	34½
12	12	26	13	13	46	30	55	27½	35½
14	14	30	15	15	48	32	58	29	37½
15	15	30	15	16½					

The dimensions given above are those adopted as a compromise by the committees responsible for the "U. S. 1912 Standard" and the competing "Manufacturers Standard," and revised by the American Engineering Standards Committee in 1921.

THE NEW AMERICAN STANDARD FOR FLANGES AND FLANGED FITTINGS. *Continued*

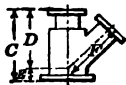
EXTRA HEAVY

Size	AA-Face to face, tees and crosses	A-Center to face, tees and crosses	B-Center to face, long radius ell	C-Center to face 45° ell	D-Face to face, laterals	E-Center to face, laterals	F-Center to face, laterals	G-Face to face, reducers	Diameter of flanges	Thickness of flanges	Minimum metal thickness of body
1	8	4	5	2	8½	6½	2	....	4¾	1¼	¾
1½	8½	4½	5½	2½	9½	7½	2½	....	5¼	¾	¾
2	9	4¾	6	3	11	8½	3	....	6¼	1¾	1½
2½	10	5	6½	3½	11½	9	3½	....	6¾	¾	1½
3	11	5½	7	4	13	10½	4	....	7¼	1	1½
3½	12	6	7¾	4½	14	11	4½	6	8¼	1¼	1½
4	13	6½	8½	5	15½	12½	5	6½	9	1½	1½
4½	14	7	9	5½	16½	13½	5½	7	10	1¾	1½
5	15	7½	9½	6	18	14½	6	7½	10½	1¾	1½
6	16	8	10¾	6½	18½	15	6½	8	11	1¾	1½
7	17	8½	11½	7	21½	17½	7	9	12½	1¾	1½
8	18	9	12½	7½	23½	19	7½	10	14	1¾	1½
9	20	10	14	8	25½	20½	8	11	15	1¾	1½
10	21	10½	15¼	8½	27½	22½	8½	11½	16¼	1¾	1½
12	23	11½	16½	9	29½	24	9	12	17½	1¾	1½
14	26	13	19	10	33½	27½	10	14	20	2	1½
15	30	15	21½	11	37½	31	11	16	23	2¼	1½
16	31	15½	22¼	11½	39½	33	11½	17	24½	2¼	1½
18	33	16½	24	12	42	34½	12	18	25½	2¼	1½
20	36	18	26½	13	45½	37½	13	19	28	2¾	1½
22	39	19½	29	14	49	40½	14	20	30½	2½	1½
24	41	20½	31½	15	53	4½	15	22	33	2¾	1½
26	45	22½	34	16	57½	47½	16	24	36	2¾	1½
28	48	24	36½	17	.	.	17	26	38¼	2¾	1½
30	52	26	39	18	.	.	18	28	40¾	2¾	1½
32	55	27½	41½	19	.	.	19	30	43	3	2
34	58	29	44	20	.	.	20	32	45¼	3¼	2¼
36	61	30½	46½	21	.	.	21	34	47½	3¼	2¼
38	65	32½	49	22	.	.	22	36	50	3¾	2¾
40	68	34	51½	23	.	.	23	38	52¼	3¾	2¾
42	71	35½	54	24	.	.	24	40	54½	3¾	2¾
44	74	37	56½	25	.	.	25	42	57	3¾	2¾
46	78	39	59	26	.	.	26	44	59¼	3¾	2¾
48	81	40½	61½	27	.	.	27	46	61½	3¾	2¾
50	84	42	64	28	.	.	28	48	65	4	3

The dimensions given above are those adopted as a compromise by the committees responsible for the "U. S. 1912 Standard" and the competing "Manufacturers' Standard," and revised by the American Engineering Standards Committee in 1921.

# 578 METALLURGISTS AND CHEMISTS' HANDBOOK

## THE NEW AMERICAN STANDARD FOR FLANGES AND FLANGED FITTINGS. *Continued*



STANDARD



EXTRA HEAVY

Size	Size of branch and smaller	C-Face to face, run	D-Center to face, run	E-Center to face, run	F-Center to face, branch	Size	Size of branch and smaller	C-Face to face, run	D-Center to face, run	E-Center to face, run	F-Center to face, branch
1	All reducing fittings 1-3½ in. inclusive have same center to face dimensions as straight size fittings.					1	All reducing fittings 1-3½ in. inclusive have same center to face dimensions as straight size fittings.				
1½						1½					
2						2					
2½						2½					
3	4	15	12	3	12	3	4	16½	13½	3	13½
3½						3½					
4						4					
4½						4½					
5	5	17	13½	3½	14½	5	5	18½	15	3½	15
6	6	18	14½	3½	14½	6	6	21½	17½	4	17½
7	7	20	16	4	16	7	7	23½	19	4½	19
8	8	22	17½	4½	17½	8	8	25½	20½	5	20½
9	9	24	19	5	19	9	9	27½	22	5½	22½
10	10	25½	20½	5	20½	10	10	29½	24	5½	24
12	12	30	24½	5½	24½	12	12	33½	27½	6	27½
14	14	33	27	6	27	14	14	37½	31	6½	31
15	15	34½	28½	6	28½	15	15	30½	31½	7	32½
16	16	36½	30	6½	30	16	16	42	34½	7½	34½
18	8	26	25	1	29½	18	8	34	31	3	32½
20	10	28	27	1	29½	20	10	37	34	3	36
22	10	29	28½	½	31½	22	10	40	37	3	39
24	12	32	31½	½	34½	24	12	44	41	3	43
26	12	35	35	0	38						
28	14	37	37	0	40						
30	14	39	39	0	42						





The dimensions given above are those adopted as a compromise by the committees responsible for the "U. S. 1912 Standard" and the competing "Manufacturers' Standard," and revised by the American Engineering Standards Committee in 1921.

## SAFE LOADS FOR ROPES AND CHAINS

(In pounds)

Prepared by National Founders' Association

CAUTION: When handling molten metal, wire ropes and chains should be 25 per cent. stronger than indicated in table.

NOTE.—The safe loads in table are for each <i>single</i> rope or chain. When used double or in other multiples the loads may be increased proportionately.			When used straight	When used at 60° angle	When used at 45° angle	When used at 80° angle
						
PLOW STEEL WIRE ROPE (6 strands of 19 or 37 wires.) If crucible steel rope is used reduce loads one-fifth.	Dia.					
	3⁄8"	1,500	1,275	1,050	750	
	1⁄2	2,400	2,050	1,700	1,200	
	5⁄8	4,000	3,400	2,800	2,000	
	3⁄4	6,000	5,100	4,200	3,000	
	7⁄8	8,000	6,800	5,600	4,000	
	1	10,000	8,500	7,000	5,000	
	1 1⁄8	13,000	11,000	9,000	6,500	
	1 1⁄4	16,000	13,500	11,000	8,000	
	1 3⁄8	19,000	16,000	13,000	9,500	
1 1⁄2	22,000	19,000	16,000	11,000		
CRANE CHAIN (Best grade of wrought iron, hand-made, tested, short link chain)	Dia. of iron					
	3⁄4"	600	500	425	350	
	5⁄8	1,200	1,025	850	600	
	1⁄2	2,400	2,050	1,700	1,200	
	5⁄8	4,000	3,400	2,800	2,000	
	3⁄4	5,500	4,700	3,900	2,750	
	7⁄8	7,500	6,400	5,200	3,700	
	1	9,500	8,000	6,600	4,700	
	1 1⁄8	12,000	10,200	8,400	6,000	
	1 1⁄4	15,000	12,750	10,500	7,500	
1 3⁄8	22,000	19,000	16,000	11,000		
MANILA ROPE (Best long fiber grade.)	Dia	Cir.				
	3⁄8"	1 "	120	100	85	60
	1⁄2	1 1⁄2	250	210	175	125
	5⁄8	2	360	300	250	180
	3⁄4	2 1⁄4	520	440	360	260
	7⁄8	2 3⁄4	620	520	420	300
	1	3	750	625	525	375
	1 1⁄8	3 1⁄2	1,000	850	700	500
	1 1⁄4	3 3⁄4	1,200	1,025	850	600
	1 1⁄2	4 1⁄2	1,600	1,350	1,100	800
	1 3⁄4	5 1⁄2	2,100	1,800	1,500	1,050
	1	6	2,800	2,400	2,000	1,400
	2 1⁄2	7 1⁄2	4,000	3,400	2,800	2,000
	2	9	6,000	5,100	4,200	3,000
	3					

ANNEALING CHAINS<sup>1</sup>

For many years The Travelers Insurance Company has recommended the periodical annealing of chains that are subject to severe usage, such as those that are used on cranes, dredges, and chain hoists, and for slings and for other heavy work, although many prominent authorities firmly believe that such treatment is inadvisable. A recent canvass of a considerable number of manufacturers shows that those in favor of the annealing process outnumber those opposed to it by about five to one, although the advocates of annealing are not in harmony as to the methods employed, the frequency of annealing, the temperature to which the chains are to be subjected, or the length of time required to insure good results.

All chain manufacturers, and practically all chain users, are aware of the fact that rough usage, shocks, and twists tend to weaken chains. A change gradually occurs in the molecular composition of the material, and the strength of the chain becomes seriously impaired. This is known as "fatigue" of the metal. There may be no visible evidence of this deterioration, although a careful microscopic examination would doubtless disclose a multitude of small cracks; but a person accustomed to the use of chains knows that deterioration is going on, and that eventually the chains will fail. When a chain has been in service for a sufficient length of time to make it unsafe for use at the load for which it was originally designed, it would be desirable to discard it, or at least to use it only for lighter loads; but such a course is not always practicable, nor, according to the views of the advocates of annealing, is it necessary, because the process of annealing counteracts the effects of fatigue and restores the chain to nearly its original strength.

As to the proper method of doing the work, a pyrometer-controlled muffle furnace is the best thing possible. Open fires are bad because it is difficult to guess the temperature of the chain, and impossible to hold the temperature steady. The Committee on Heat Treatment, of the American Society for Testing Materials, recommends the following annealing temperatures.

Carbon content	Annealing temperature
Less than 0.12 per cent . . . . .	875-925°C. (1607-1697°F.)
0.12-0.25 per cent . . . . .	840-870°C. (1544-1598°F.)
0.30-0.49 per cent . . . . .	815-840°C. (1499-1544°F.)
0.50-1.00 per cent . . . . .	790-815°C. (1454-1499°F.)

If an open fire must be used, heat to a cherry red in a wood fire, then let the fire die out, and allow the chain to cool in the ashes. •

Various methods for testing chains are employed by persons who have no faith in the annealing process. The method advocated by the Yale & Towne Manufacturing Co. and by the Brown & Sharpe Manufacturing Co. is to make use of a gage 3

<sup>1</sup> From the "Travelers Standard" p. 122, 1915.



ft. long. Every new chain is marked with a prick-punch at intervals of 3 ft., and at each subsequent inspection of the chain the prick-punch marks are compared with the gage. If it is found that a section of the chain between two of the marks has stretched by an amount equal to one-third of the length of a link, the chain is considered unsafe and is condemned, or is used in some place where it will be subjected only to light loads. It is sometimes found that only a single section of the chain must be discarded. The experience of users of chains who have adopted this method for testing them has been satisfactory, in the main, the accidents from breaking chains have been materially reduced by it. Manifestly, however, it would not apply without modification to chains having unusually large links.

Many authorities on chains, even though admitting that sling chains should be annealed, insist that block chains that pass over sheaves should not be treated in this way. The danger from molecular changes caused by overloading the chains may be greatly diminished by proper annealing, but when distortion of the links occurs in block chains the chains no longer fit the sheaves, and excessive wear results, often accompanied by severe and badly distributed stresses. No amount of annealing can restore the links to their original lengths, and the only practical remedy, when such distortion has occurred, is to substitute new chains.

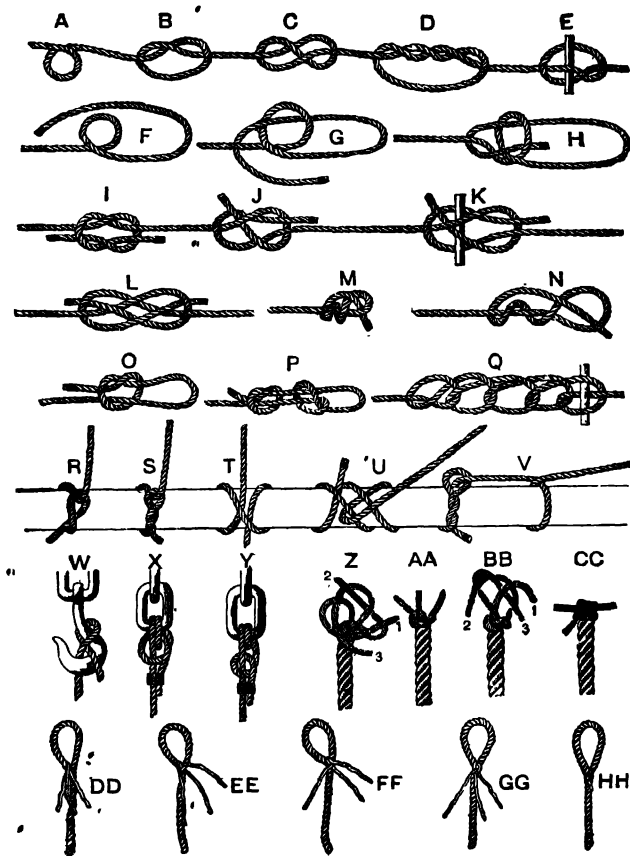
### FIBER ROPE KNOTS AND HITCHES—AND HOW TO MAKE THEM

The principle of a knot is that no 2 parts which would move in the same direction if the rope were to slip, should lie alongside of and touching each other. This principle is clearly shown in the square knot (I).

A great number of knots have been devised, of which a few of the most useful are herewith illustrated by courtesy of C. W. Hunt Company, of New York. In the engravings they are shown open, or before being drawn taut, in order to show the position of the parts. The names usually given to them are:

- A. Bight of a rope.
- B. Simple or overhand knot
- C. Figure 8 knot.
- D. Double knot.
- E. Boat knot.
- F. Bowline, first step.
- G. Bowline, second step.
- H. Bowline, completed.
- I. Square or reef knot.
- J. Sheet bend or weaver's knot.
- K. Sheet bend with a toggle.
- L. Carrick bend.
- M. "Stevedore" knot completed.
- N. "Stevedore" knot commenced.

- O. Slip knot.  
 P. Flemish loop.  
 Q. Chain knot with toggle.  
 R. Half-hitch.  
 S. Timber-hitch.  
 T. Clove-hitch.  
 U. Rolling-hitch.  
 V. Timber-hitch and half-hitch.  
 W. Blackwall-hitch.



- X. Fisherman's bend.
- Y. Round turn and half-hitch.
- Z. Wall knot commenced.
- AA. Wall knot completed.
- BB. Wall knot crown commenced.
- CC. Wall knot crown completed.
- DD to HH. Eye splice commenced and completed.

The bowline (G) is one of the most useful knots; it will not slip, and after being strained is easily untied. It should be tied with facility by everyone who handles rope. Commence by making a bight in the rope, then put the end through the bight and under the standing part, as shown in the engraving, then pass the end again through the bight, and haul tight.

The square or reef knot (I) must not be mistaken for the "granny" knot that slips under a strain. Knots (H, K and M) are easily untied after being under strain. The knot (M) is useful when the rope passes through an eye and is held by the knot, as it will not slip, and is easily untied after being strained.

The wall knot looks complicated, but is easily made by proceeding as follows:

Form a bight with strand 1, and pass the strand 2 around the end of it, and the strand 3 around the end of 2, and then through the bight of 1, as shown in engraving Z. Haul the ends taut, when the appearance is as shown in the engraving AA. The end of the strand 1 is now laid over the center of the knot, strand 2 laid over 1, and 3 over 2, when the end of 3 is passed through the bight of 1, as shown in the engraving BB. Haul all the strands taut, as shown in the engraving CC.

The "stevedore" knot (M), (N) is used to hold the end of a rope from passing through a hole. When the rope is strained the knot draws up tight, but it can be easily untied when the strain is removed.

If a knot or hitch of any kind is tied in a rope, its failure under stress is sure to occur at that place. Each fiber in the straight part of the rope takes proper share of the load, but in all knots the rope is cramped or has a short bend, which throws an overload on those fibers that are on the outside of the bend and one fiber after another breaks until the rope is torn apart. The shorter the bend in the standing rope, the weaker is the knot.

The curvature of wire ropes over pulleys should be such that the bending stress plus the load stress will not produce a tension in the wires greater than the elastic limit.

$$\text{The bending stress in lb.} = \frac{Ea}{2.06 \frac{R}{d} + c}$$

where  $E$  = the modulus of elasticity;  $R$  = radius of bend in inches;  $d$  = diameter of the individual wires in inches; and  $C$  = a constant depending on the number of wires in the strands (for 7-wire rope  $C = 9.27$ ; for 12-wire, 12.36; for 15-wire, 15.45).

The tension of a rope is measured by its sag at the center of the arc. Let  $h$  = deflection in ft.;  $w$  = wt. of rope in lb. per running foot;  $t$  = tension;  $l$  = chord of arc in ft.; then  $h = \frac{wl^2}{8t}$

### HOW TO SPLICE WIRE ROPE<sup>1</sup>

The accompanying illustrations show how a substantial wire-rope splice may be effected. A hammer and a cold chisel for cutting off ends of strands, a steel fid or marlinspike for separating strands, two clamps for untwisting the rope, a sharp pocket knife for cutting the hemp core and a wooden mallet are all the tools needed. When starting to splice, proceed in this order:

First, lay the rope on the ground, with ends overlapping 20 ft., 10 ft. each way from the center, as shown in Fig. 1.

Second, unlay the strands of both ends of the rope for a distance of 10 ft., as shown in Fig. 2. Cut off the hemp cores close up on both sides and bring the strands together so that the opposite strands will interlock regularly with each other.

Third, unlay strand 1a and follow up with strand 1 of the other end, laying it tightly in the open groove made by unwinding 1a; make the twist of the strand agree exactly with the twist of the open groove. Proceed with this until all but 6 in. of strand 1 is laid in or until 1a has become 20 ft. long, then cut off 1a, leaving an end about 6 in. long.

Fourth, unlay strand 4 of the opposite end and follow with strand 4a, laying it in the open groove as before, treating this as the first case (see Fig. 3). Pursue the same course with 2a and 2, stopping 4 ft. short of the first set. Next do this with 5 and 5a, stopping as before, then with 3a and 3, and last with 6 and 6a. The strands are now all laid in with the ends 4 ft. apart, as shown in Fig. 4.

Fifth and last, the ends must be secured without enlarging the diameter of the rope. Take the two rope clamps, as shown in Fig. 6, and fasten them to the rope, as shown in Fig. 5. Twist them in opposite directions, thus opening the lay of the rope, as in Fig. 5. Next with a knife cut out the hemp core about 6 in. on each side. Straighten the ends and slip them into the place occupied by the core; then twist the clamps back, closing up the rope, and take out the slight inequality with the wooden mallet and a block of wood. Next shift the clamps and repeat the operation at the other five places, and the splice is made.

<sup>1</sup> By C. J. FUETTER, Logan, W. Va., in *Coal Age*, Nov. 20, 1915

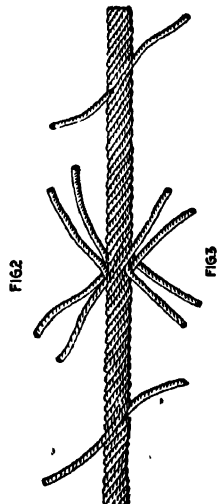
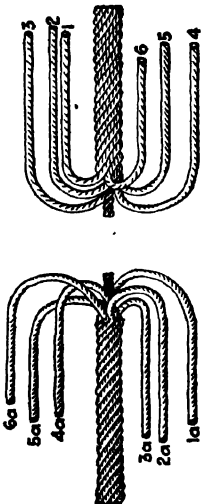
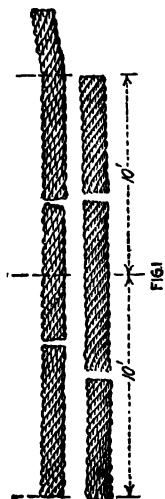
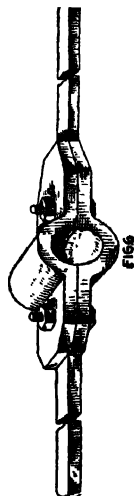
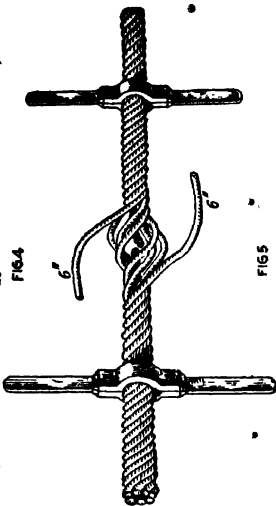
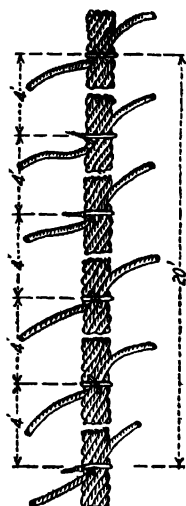


FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

# 586 METALLURGISTS AND CHEMISTS' HANDBOOK

## FORMULAS\*FOR PUMPS AND PIPING<sup>1</sup>

To find	Give	Formulas
1. Pressure in lb. per sq. in. = $P$ .	Head in ft. = $H$	$P = H \times 0.433$ .
2. Head in ft. = $H$ .	Pressure in lb. per sq. in. = $P$ .	$H = P \times 2.312$ .
3. Horsepower required to raise water (theoretical).	Gal. per min. = $G$ Head in ft. = $H$ .	$H.p. = \frac{G \times H}{3,300}$
4. Volume of water discharged by pipe (neglecting bends and friction).	*Internal dia. of pipe in in. = $D$ . Head in ft. = $H$ . Length of pipe in yards = $L$ .	Gal. per min.: = $28 \sqrt{\frac{D^5 \times H}{L}}$
5. Theoretical capacity of single-acting pump.	Area of ram in in. = $A$ . Stroke in in. = $S$ . No. of strokes per min. = $N$ .	Gal. per min.: = $\frac{A \times S \times N \times 6.25}{1728}$
6. Dia. in in. of single-acting pump to deliver given number of gals. per stroke.	Gal. per stroke = $G$ . Stroke in ft. = $S$ .	Dia. of pump = $\sqrt{\frac{31G}{S}}$ (allowing 5 per cent. waste).
7. Feet head lost by friction in pipes = $F$ .	*Gal. per min. = $G$ . Length of pipe in yards = $L$ . Internal dia. of pipe in in. = $D$ .	$F = \frac{G^2 \times L}{(3D)^5}$
8. Approx. weight of water in vertical pipes in lb. = $W$ .	Internal dia. of pipe in in. = $D$ . Length of pipe in yards = $L$ .	$W = D^2 \times L$ .
9. Thickness of cast-iron pipes in in. = $T$ .	Internal dia. of pipe in in. = $D$ . Pressure in lb. per sq. in. = $P$ .	$T = \frac{D \times P}{4,000} + 0.3$ .
10. Delivery per stroke of single-acting pump.	Dia. of plunger in in. = $D$ . Stroke in ft. = $S$ .	Gal. delivered per stroke = $\frac{D^2 \times S}{31}$ (allowing 5 per cent. waste).
11. Speed of water through pipes in ft. per sec.	Area in pipe in in. = $A$ . Discharge in cu. ft. per min. = F.P.M.	Velocity ft. per sec. = $\frac{F.P.M. \times 2.4}{A}$
12. Velocity in ft. per sec. due to head = $V$ .	$H$ = head. $g = 32.2$ .	$V = \sqrt{2gH}$
13. Head from velocity.		$H = \frac{V^2}{2g}$
14. Imperial gallons..	Cubic feet = $C$	Imperial gallons = $C \times 6.25$ .
15. Cubic feet . . . .	Gallons (Imperial) = $G$ .	Cubic feet = $G \times 0.16$ .

<sup>1</sup> G. S. BURROWS, in *American Machinist*, Aug. 20, 1914.

# EFFECT OF FITTINGS ON FLOW OF FLUIDS THROUGH PIPE LINES

DEAN E. FOSTER presented the accompanying pipefitting equivalent tables and steam flow chart at the annual meeting of the A.S.M.E., New York, Dec. 7-10, 1919. To illustrate, an example may be taken of a 6-in. steam line 1,000 ft. long, containing five gate valves, three angle valves, twenty standard tees and ten standard elbows. From the lower table for vapors, these fittings are found to be equivalent to 332.10 ft. of 6-in. pipe, as follows:

5 gate valves at 4.81 .....	24.05
3 angle valves at 17.35 .....	52.05
20 standard tees at 6.35 .....	127.00
10 standard elbows at 12.90 .....	129.00
Total allowance. ....	332.10
Actual pipe length.....	1,000.00
Equivalent total length.....	1,332.10

The chart shows that with an initial pressure of 150 lb. and a total loss of 5 lb. pressure or 0.375 lb. per 100 ft. this line will transmit 225 lb. of steam per minute. If the effect of the valves and fittings had been ignored, the calculation would show a capacity of 260 lb. of steam per minute.

The upper table for liquid flow is used in conjunction with standard tables, Cox's flow of water through pipes, etc., in a similar manner. In both formulas,

$L_e$  = feet of pipe equivalent to fitting.

$d$  = diameter of pipe in inches.

$r$  = factor of resistance.

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## STANDARD PIPE EQUIVALENTS TO ALLOW FOR FITTINGS Conduits Carrying Non-viscous Liquids

(Formula Used:  $L_e = 53.75rd^{1.25}$ )

Nominal pipe size, in.	Actual inside diameter, in.	Gate valve	Long-sweep el. or standard tee	Medium-sweep elbow or tee red. in size $\frac{1}{4}$	Standard elbow or tee reduced in size $\frac{1}{2}$	Angle valve	Close return bend	Tee through side outlet	Globe valve
Factor of resistance		0.25	0.33	0.42	0.67	0.90	1.00	1.33	2.00
$\frac{1}{2}$	0.662	0.335	0.442	0.56	0.89	1.20	1.34	1.79	2.68
$\frac{3}{4}$	0.824	0.475	0.627	0.79	1.27	1.71	1.90	2.52	3.80
1	1.049	0.640	0.844	1.07	1.72	2.30	2.56	3.40	5.12
$1\frac{1}{4}$	1.38	0.902	1.19	1.51	2.42	3.24	3.61	4.80	7.22
$1\frac{1}{2}$	1.61	1.09	1.43	1.83	1.92	3.92	4.36	5.79	8.72
2	2.06	1.49	1.96	2.50	3.99	5.36	5.96	7.92	11.92
$2\frac{1}{2}$	2.46	1.86	2.46	3.13	5.00	6.72	7.47	9.93	14.94
3	3.06	2.46	3.25	4.11	6.66	8.87	9.86	13.11	19.72
$3\frac{1}{2}$	3.54	2.92	3.80	4.91	7.84	10.53	11.70	15.56	23.40
4	4.026	3.44	4.53	5.77	9.22	12.37	13.70	18.28	27.50
$4\frac{1}{2}$	4.506	3.95	5.20	6.63	10.60	14.22	15.80	21.01	31.60
5	5.047	4.57	6.00	7.68	12.20	16.47	18.30	24.33	36.60
6	6.065	5.72	7.55	9.61	15.30	20.61	22.90	30.45	45.80
7	7.024	6.90	9.10	11.59	18.50	24.84	27.60	36.70	55.20
8	7.981	8.10	10.69	13.60	21.70	29.16	32.40	43.09	64.80
10	10.020	10.70	14.10	17.97	28.70	38.52	42.80	56.92	85.60
12	12.090	12.50	17.80	22.68	36.20	48.60	54.00	71.82	108.00

## Conduits Carrying Vapors or Gas

(Formula Used:  $L_e = 43.7rd^{1.2}$ )

Factor of resistance		0.25	0.33	0.42	0.67	0.90	1.00	1.33	2.00
$\frac{1}{2}$	0.622	0.031	0.41	0.52	0.84	1.12	1.25	1.66	2.50
$\frac{3}{4}$	0.824	0.044	0.57	0.73	1.17	1.57	1.75	2.33	3.50
1	1.049	0.057	0.77	0.98	1.57	2.11	2.34	3.11	4.68
$1\frac{1}{4}$	1.380	0.082	1.07	1.37	2.19	2.94	3.27	4.35	6.54
$1\frac{1}{2}$	1.610	0.098	1.29	1.64	2.63	3.52	3.92	5.21	7.84
2	2.067	1.32	1.74	2.23	3.55	4.77	5.30	7.05	10.60
$2\frac{1}{2}$	2.469	1.64	2.16	2.75	4.39	5.91	6.56	8.71	13.12
3	3.068	2.13	2.81	3.59	5.72	7.69	8.54	11.40	17.08
$3\frac{1}{2}$	3.548	2.53	3.34	4.26	6.80	9.10	10.13	13.50	20.26
4	4.026	2.96	3.90	4.97	7.94	10.65	11.84	15.75	23.68
$4\frac{1}{2}$	4.506	3.27	4.45	5.66	9.05	12.14	13.50	17.95	27.00
5	5.047	3.88	5.11	6.42	10.40	13.95	15.51	20.60	31.02
6	6.065	4.81	6.35	8.09	12.90	17.35	19.27	25.60	38.54
7	7.023	5.75	7.59	9.66	15.40	20.70	23.02	30.60	46.08
8	7.981	6.70	8.85	11.20	17.90	24.10	26.80	35.60	53.60
10	10.02	8.75	11.54	14.70	23.40	31.50	35.00	46.60	70.00
12	12.09	10.90	14.40	18.35	29.30	39.30	43.70	58.10	87.40



With two fans pulling air from the same flue: if  $A$  is the volume of gas handled by the first fan alone, and  $B$  the volume handled by the second fan alone, both together will handle  $\sqrt[3]{A^3 + B^3}$ .

## WATER PRESSURE AT VARIOUS HEADS

Feet head	Pounds per sq. in.	Feet head	Pounds per sq. in.	Feet head	Pounds per sq. in.	Feet head	Pounds per sq. in.	Feet head	Pounds per sq. in.
.....	.....	130	56.31	195	84.47	260	112.62	350	151.61
.....	.....	135	58.48	200	86.63	265	114.79	360	155.94
.....	.....	140	60.64	205	88.80	270	116.96	370	160.27
.....	.....	145	62.81	210	90.96	275	119.12	380	164.61
.....	.....	150	64.97	215	93.14	280	121.29	390	168.94
.....	.....	155	67.14	220	95.30	285	123.45	400	173.27
.....	.....	160	69.31	225	97.49	290	125.62	450	194.92
.....	.....	165	71.47	230	99.63	295	127.78	500	216.58
100	43.31	170	73.64	235	101.79	300	129.95	550	238.24
105	45.48	175	75.80	240	103.96	310	134.28	600	259.90
110	47.64	180	77.97	245	106.13	320	138.62	650	281.56
115	49.81	185	80.14	250	108.29	330	142.95	700	303.22
120	51.98	190	82.30	255	110.46	340	147.28	750	324.88
125	54.15							800	346.54
								850	368.20
								900	389.86
								950	411.52
								1000	433.18

For heads under 100 ft., take the figure corresponding to 10 (or 100) times the given head and move the decimal point one (or two) places to the left.

Flow of Gas in Pipes<sup>1</sup>

If  $d$  = Diameter of pipe in inches.

$Q$  = Quantity of gas in cu. ft. per hour.

$l$  = Length of pipe in yards.

$h$  = Pressure in inches of water.

$s$  = Specific gravity of gas, air being 1,

then

$$d = \sqrt[5]{\frac{Q^2 s l}{(1350)^2 h}}$$

$$h = \frac{Q^2 s l}{(1350)^2 d^5}$$

$$Q = 1350 d^2 \sqrt{\frac{d h}{s l}} = 1350 \sqrt{\frac{d^5 h}{s l}}$$

or MOLESWORTH gives  $Q = 1000 \sqrt{\frac{d^5 h}{s l}}$

while J. P. GILL gives  $Q = 1291 \sqrt{\frac{d^5 h}{s(l+d)}}$

<sup>1</sup> KENT, "Mechanical Engineers' Pocket Book."

Flow of Fluids in Pipes.<sup>1</sup>

## Notation:

 $v$  = mean velocity of fluid, ft. per sec. $R$  = hydraulic radius of duct. $S$  = hydraulic slope. $P$  = pressure absorbed by friction, lb. per sq. ft. $p$  = pressure absorbed by friction; lb. per sq. in. $A$  = sectional area of duct, sq. ft. $O$  = perimeter of duct, ft. $L$  = length of duct, ft. $d$  = diameter of cylindrical duct, inches. $w$  = density of the fluid, lb. per cu. ft. $g$  = sp. gr. =  $w \div 62.4$ . $C, k$  and  $B$ , coefficients to be described below. $n$  = a coefficient for roughness.(a) The slope formula,  $v = C\sqrt{RS}$ .(b) The ventilation formula,  $v = \frac{1}{60}\sqrt{\frac{PA}{kOL}}$ .(c) The pipe formula,  $v = B\sqrt{\frac{pd}{wL}}$ . $C$  = KUTTER'S coefficient. $k$  = ATKINSON'S coefficient. $B$  = A coefficient for studying flow of waters, gases and vapors in pipes.

$$C = \frac{1}{60}\sqrt{\frac{w}{k}} = \frac{B}{\sqrt{3}}$$

$$S = \frac{v^2}{C^2 R} = \frac{3,600 kv^2}{WR} = \frac{3v^2}{B^2 R}$$

$$41.6 + \frac{0.00281}{gs} + \frac{1.811}{n}$$

$$C = \frac{1}{1 + \left(41.6 + \frac{0.00281}{gs}\right)n} \sqrt{r}$$

$$gS = g \frac{144p}{62.4gL} = 2.308 \frac{p}{L}$$

The above equation is only true for water if  $R$  is less than 3.28.VALUES FOR  $C$  FOR WATER ( $n = 0.010$ )

$S =$	0.0001	0.001	0.01
$R = 1.00$	147	155	156
$R = 3.28$	181	181	181
$R = 16.00$	205	197	196

<sup>1</sup> Trans. A.I.M.E., Pittsburgh meeting, 1926.

## BABCOCK FORMULA FOR STEAM

$$B = \frac{265.9}{1 + \frac{3.6}{d}}$$

The formula for  $B$  as applied to equation (c) is of little value for velocities below 1,000 ft. per sec.

## GOODENOUGH FORMULA FOR AIR IN SMOOTH CONCRETE DUCTS

$$10^3k = \left(1\,5115 + \frac{12\,382}{v^2R^2}\right)w.$$

VALUES OF  $n$  (WATER AND VENTILATION)

For smooth concrete pipe. . . . .	0 010
For galvanized pipe . . . . .	0 010
For canvas pipe . . . . .	0 011-0 012
For coal-mine entires. . . . .	0.019-0 020
For timbered headings . . . . .	0 029
For igneous rocks . . . . .	0 035

TABLE FOR CONVERTING "COMPRESSED AIR" INTO "FREE AIR"<sup>1</sup>

Altitude	Barometer	Atmospheric pressure	Gage pressure													
			45	50	55	60	65	70	75	80	85	90	95	100	105	110
0	30.00	14.7	4.06	4.40	4.74	5.08	5.42	5.76	6.10	6.44	6.78	7.12	7.46	7.80	8.14	8.48
500	29.45	14.45	4.11	4.46	4.80	5.15	5.50	5.83	6.19	6.53	6.88	7.23	7.57	7.92	8.26	8.61
1,000	28.90	14.12	4.18	4.54	4.89	5.24	5.60	5.95	6.31	6.66	7.02	7.37	7.72	8.08	8.43	8.79
1,500	28.35	13.92	4.23	4.59	4.95	5.31	5.67	6.03	6.39	6.75	7.10	7.46	7.82	8.18	8.54	8.90
2,000	27.78	13.61	4.30	4.67	5.05	5.41	5.77	6.14	6.51	6.88	7.24	7.61	7.98	8.34	8.71	9.08
3,000	26.75	13.10	4.43	4.81	5.20	5.58	5.96	6.34	6.72	7.10	7.49	7.87	8.25	8.63	9.01	9.40
4,000	25.75	12.61	4.57	4.96	5.36	5.76	6.15	6.55	6.95	7.34	7.74	8.14	8.53	8.93	9.32	9.72
5,000	24.78	12.15	4.70	5.11	5.52	5.94	6.35	6.76	7.17	7.58	7.99	8.40	8.82	9.22	9.64	10.05
6,000	23.86	11.75	4.83	5.24	5.68	6.16	6.53	6.96	7.38	7.81	8.23	8.66	9.08	9.51	9.93	10.36
7,000	22.97	11.27	4.99	5.43	5.88	6.32	6.77	7.21	7.65	8.10	8.54	8.98	9.43	9.87	10.32	10.76
8,000	22.10	10.85	5.14	5.61	6.07	6.53	6.99	7.45	7.91	8.37	8.83	9.29	9.75	10.21	10.68	11.14
9,000	21.30	10.45	5.31	5.78	6.26	6.74	7.22	7.70	8.19	8.67	9.13	9.61	10.09	10.57	11.05	11.52
10,000	20.60	10.10	5.45	5.95	6.44	6.94	7.43	7.93	8.42	8.92	9.41	9.91	10.40	10.90	11.40	11.88

*Example:* Given 348 cu. ft. of air compressed to 95 lb. pressure at 4000 ft. altitude. Opposite 4000 and below 95 appears the figure 8.53.  $8.53 \times 348 = 2968.44 =$  volume in "free air."

<sup>1</sup> Sullivan Machinery Co.'s Catalogue.

# HORSEPOWER (THEORETICAL) REQUIRED TO COMPRESS 100 CU. FT. FREE AIR TO VARIOUS PRESSURES<sup>1</sup>

Gage pressure	Single-stage	Two-stage	Saving of two-stage over single-stage compression	
			Horsepower	Per cent.
5	1.97	.....	.....	.....
10	3.61	.....	.....	.....
15	5.02	.....	.....	.....
20	6.28	.....	.....	.....
25	7.44	.....	.....	.....
30	8.45	.....	.....	.....
35	9.41	.....	.....	.....
40	10.30	.....	.....	.....
45	11.13	.....	.....	.....
50	11.92	10.65	1.28	10.70
55	12.67	11.25	1.42	11.22
60	13.37	11.81	1.57	11.72
65	14.05	12.34	1.71	12.18
70	14.70	12.84	1.85	12.61
75	15.32	13.32	2.00	13.04
80	15.91	13.77	2.13	13.40
85	16.48	14.21	2.27	13.77
90	17.04	14.63	2.41	14.12
95	17.57	15.03	2.54	14.45
100	18.09	15.42	2.67	14.77
110	19.08	16.15	2.93	15.36
120	20.01	16.83	3.18	15.90
130	20.90	17.46	3.43	16.42
140	21.74	18.07	3.67	16.89
150	22.55	18.64	3.91	17.33
160	23.32	19.26	4.06	17.40
170	24.06	19.78	4.29	17.80
180	24.77	20.27	4.51	18.18
190	25.46	20.74	4.70	18.46
200	26.12	21.19	4.93	18.88
210	.....	21.54	.....	.....
220	.....	21.96	.....	.....
230	.....	22.37	.....	.....
240	.....	22.76	.....	.....
250	.....	23.03	.....	.....
260	.....	23.28	.....	.....
270	.....	23.84	.....	.....
280	.....	24.19	.....	.....
290	.....	24.53	.....	.....
300	.....	24.85	.....	.....
350	.....	26.35	.....	.....
400	.....	27.65	.....	.....
450	.....	28.85	.....	.....
500	.....	29.97	.....	.....

To secure the actual horsepower required to compress a given volume of air to any desired pressure, 10 to 15 per cent. should be added to the figures shown above, depending upon the size and type of the compressor, to allow for mechanical losses.

<sup>1</sup> Sullivan Machinery Co.'s Catalog.

# 594 METALLURGISTS AND CHEMISTS' HANDBOOK

## APPROXIMATE CUBIC FEET OF FREE AIR AND WORKING PRESSURE REQUIRED TO RAISE 1 GAL. OF WATER BY AIR LIFT<sup>1</sup>

$$V = \frac{L}{H + 34} \times 292.5$$

H = Submergence in feet.

L = Lift in feet.

Ft. lb. working power = submergence  $\times$  0.4465 + 7 lb.

V = Volume of free air per gallon in cubic feet.

### RATIO OF SUBMERGENCE TO LIFT

Lift in feet	25 per cent. $\frac{1}{4}-1$			33 per cent. $\frac{1}{2}-1$			43 per cent. $\frac{3}{4}-1$			50 per cent. 1-1			
	Free air, cu. ft.	Working pressure	Horse-power	F. A. C. F.	W. P.	H. P.	F. A. C. F.	W. P.	H. P.	F. A. C. F.	W. P.	H. P.	
20										0.34	16	.018	1-Stage
30										0.38	20	.024	
40										0.41	25	.031	
50										0.44	29	.036	
60										0.47	34	.043	
80										0.52	43	.056	
100							0.68	40	.070	0.58	52	.071	
120							0.73	47	.084	0.63	61	.075	2-Stage
140							0.79	54	.099	0.68	70	.087	
160							0.84	61	.100	0.73	78	.099	
180							0.88	67	.110	0.77	88	.111	
200	1.44	37	.141	1.15	52	.141	0.93	74	.123	0.82	96	.124	
250	1.57	44	.172	1.27	63	.154	1.05	91	.154	0.92	119	.154	
300	1.69	52	.207	1.40	74	.186	1.20	107	.191	1.03	141	.187	
350	1.82	59	.241	1.50	85	.213	1.31	124	.224	1.16	163	.225	3-Stage
400	1.96	66	.244	1.63	96	.246	1.38	141	.250	1.23	186	.253	
450	2.08	74	.276	1.74	107	.277	1.48	157	.282	1.33	208	.267	
500	2.19	82	.306	1.86	119	.312	1.56	174	.312	1.43	230	.299	
550	2.30	88	.333	1.96	130	.342	1.64	191	.349	1.52	253	.329	
600	2.41	96	.364	2.05	141	.372	1.74	208	.358	1.61	275	.360	
650	2.52	104	.396	2.18	152	.409	1.87	226	.388	1.74	297	.400	
700	2.64	111	.428	2.27	163	.441	1.96	240	.416	1.81	320	.427	
750	2.76	119	.463	2.37	174	.473	2.06	258	.450	1.88	342	.454	
800	2.88	126	.496	2.47	186	.508	2.15	275	.480	1.97	364	.486	
850	2.97	133	.524	2.57	197	.542	2.24	292	.512	2.06	387	.519	
900	3.07	141	.557	2.67	208	.537	2.33	308	.542	2.14	409	.550	
950	3.18	149	.591	2.76	219	.566	2.40	325	.567	2.22	431	.579	
1000	3.28	156	.622	2.86	230	.598	2.77	342	.609	2.31	453	.614	

<sup>1</sup> Sullivan Machinery Co.'s Catalog.

**APPROXIMATE CUBIC FEET OF FREE AIR AND WORKING PRESSURE  
REQUIRED TO RAISE 1 GAL. OF WATER BY AIR LIFT. *Continued***

Lift in feet	55 per cent. 1½-1			60 per cent. 1½-1			66 per cent. 2-1			70 per cent. 2½-1			
	F. A. C. F.	W. P.	H. P.	F. A. C. F.	W. P.	H. P.	F. A. C. F.	W. P.	H. P.	F. A. C. F.	W. P.	H. P.	
20	0.29	18	.017	0.25	20	.016	0.20	25	.015	0.17	29	.014	1-Stage
30	0.32	24	.023	0.28	27	.022	0.23	34	.021	0.20	40	.021	
40	0.35	29	.029	0.31	34	.029	0.26	43	.028	0.23	52	.028	
50	0.38	35	.036	0.34	40	.035	0.29	52	.035	0.26	63	.032	
60	0.41	40	.042	0.37	47	.042	0.32	61	.038	0.28	74	.037	
70	0.46	52	.056	0.42	61	.050	0.36	78	.049	0.33	96	.050	2-Stage
100	0.51	63	.062	0.47	74	.062	0.41	96	.062	0.37	119	.062	
120	0.56	74	.074	0.52	87	.075	0.46	114	.076	0.42	141	.076	
140	0.61	85	.087	0.56	101	.087	0.50	132	.088	0.46	163	.089	
160	0.66	96	.100	0.60	114	.099	0.54	150	.101	0.50	186	.103	
180	0.70	108	.112	0.65	127	.112	0.58	168	.114	0.54	208	.109	3-Stage
200	0.74	119	.124	0.69	141	.125	0.62	186	.127	0.58	230	.121	
250	0.86	147	.159	0.79	174	.158	0.72	230	.151	0.67	286	.152	
300	0.96	174	.192	0.89	208	.179	0.81	275	.181	0.76	342	.184	
350	1.05	202	.209	0.98	241	.209	0.89	320	.211	0.84	398	.214	
400	1.14	230	.238	1.08	275	.241	0.98	364	.242	0.93	453	.247	
450	1.23	258	.269	1.17	308	.272	1.07	409	.275	1.02	509	.282	
500	1.32	286	.299	1.26	342	.304	1.15	453	.306	1.09	565	.308	
550	1.42	328	.338	1.34	375	.334	1.25	498	.343	...	...	...	
600	1.51	342	.365	1.42	409	.365	1.31	543	.369	...	...	...	
650	1.61	370	.400	1.52	442	.401	1.30	587	.402	...	...	...	
700	1.68	398	.428	1.60	476	.432	1.47	622	.435	...	...	...	
750	1.78	425	.463	1.66	509	.458	1.55	677	.468	...	...	...	
800	1.86	453	.494	1.75	543	.493	1.65	721	.507	...	...	...	
850	1.93	481	.523	1.82	576	.523	1.70	766	.533	...	...	...	
900	2.00	509	.552	1.86	610	.544	1.77	811	.564	...	...	...	
950	2.08	536	.584	1.99	643	.591	1.85	855	.599	...	...	...	
1000	2.17	565	.618	2.06	677	.622	1.93	900	.634	...	...	...	

VOLUMETRIC AND HORSEPOWER COEFFICIENTS FOR TWO-STAGE AIR COMPRESSION<sup>1</sup>

Altitude, in feet.		Barom. press., in lb. per sq. in.	Terminal gage pressure, pounds per square inch.													
			70		80		90		100		120		140		150	
			H.p. coeff.	Volum. coeff.	H.p. coeff.	Volum. coeff.	H.p. coeff.	Volum. coeff.	H.p. coeff.	Volum. coeff.	H.p. coeff.	Volum. coeff.	H.p. coeff.	Volum. coeff.	H.p. coeff.	Volum. coeff.
Sea level	14.72	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1,000	14.17	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97	
2,000	13.64	0.97	0.94	0.96	0.94	0.96	0.94	0.96	0.94	0.96	0.93	0.96	0.93	0.96	0.93	
3,000	13.13	0.95	0.91	0.95	0.91	0.94	0.91	0.94	0.91	0.94	0.90	0.94	0.90	0.94	0.90	
4,000	12.64	0.93	0.88	0.93	0.88	0.93	0.88	0.92	0.88	0.92	0.87	0.92	0.87	0.92	0.87	
5,000	12.17	0.91	0.85	0.91	0.85	0.91	0.85	0.91	0.85	0.90	0.84	0.90	0.84	0.90	0.84	
6,000	11.71	0.90	0.82	0.89	0.82	0.89	0.82	0.89	0.82	0.88	0.82	0.88	0.81	0.88	0.81	
7,000	11.27	0.88	0.80	0.88	0.79	0.87	0.79	0.87	0.79	0.86	0.79	0.86	0.78	0.86	0.78	
8,000	10.85	0.86	0.77	0.86	0.77	0.85	0.77	0.85	0.76	0.85	0.76	0.84	0.76	0.84	0.76	
9,000	10.45	0.85	0.75	0.84	0.74	0.84	0.74	0.83	0.74	0.83	0.73	0.82	0.73	0.82	0.73	
10,000	10.06	0.83	0.72	0.83	0.72	0.82	0.72	0.82	0.71	0.81	0.71	0.81	0.71	0.80	0.70	
11,000	9.69	0.82	0.70	0.81	0.70	0.80	0.69	0.80	0.69	0.79	0.68	0.79	0.68	0.79	0.68	
12,000	9.33	0.80	0.68	0.79	0.67	0.79	0.67	0.78	0.67	0.78	0.66	0.77	0.66	0.77	0.66	
13,000	8.98	0.78	0.65	0.78	0.65	0.77	0.65	0.77	0.64	0.76	0.64	0.75	0.63	0.75	0.63	
14,000	8.64	0.77	0.63	0.77	0.63	0.76	0.62	0.75	0.62	0.74	0.62	0.74	0.61	0.74	0.61	
15,000	8.32	0.75	0.61	0.74	0.61	0.74	0.60	0.74	0.60	0.73	0.59	0.72	0.59	0.72	0.59	

<sup>1</sup> Sullivan Machinery Co.'s Catalog.



HORSEPOWER PER 100 CUBIC FEET FREE AIR PER MINUTE, TWO-STAGE COMPRESSION; THEORETICAL  
HORSEPOWER IN AIR CYLINDERS<sup>1</sup>  
(Allow for Friction and other Losses)

Altitude in feet	Barom. press., lb. per sq. in.	Terminal gage pressure											
		70	75	80	85	90	95	100	110	120	130	140	150
Sea level	14.72	12.84	13.32	13.78	14.21	14.63	15.03	15.42	16.15	16.83	17.47	18.07	18.64
1,000	14.17	12.62	13.08	13.52	13.95	14.35	14.74	15.12	15.83	16.49	17.11	17.69	18.25
2,000	13.64	12.39	12.84	13.27	13.68	14.08	14.46	14.82	15.51	16.15	16.76	17.33	17.86
3,000	13.13	12.17	12.61	13.03	13.43	13.81	14.18	14.53	15.20	15.83	16.41	16.96	17.48
4,000	12.64	11.94	12.37	12.78	13.17	13.54	13.90	14.25	14.90	15.50	16.07	16.61	17.11
5,000	12.17	11.72	12.14	12.54	12.92	13.28	13.63	13.96	14.60	15.19	15.74	16.25	16.75
6,000	11.71	11.51	11.91	12.30	12.66	13.02	13.35	13.68	14.29	14.86	15.40	15.90	16.38
7,000	11.27	11.29	11.68	12.06	12.41	12.76	13.09	13.40	14.00	14.55	15.07	15.56	16.02 <sup>2</sup>
8,000	10.85	11.07	11.46	11.83	12.17	12.50	12.82	13.13	13.71	14.25	14.75	15.22	15.67
9,000	10.45	10.87	11.24	11.59	11.93	12.26	12.57	12.86	13.42	13.95	14.44	14.90	15.33
10,000	10.06	10.66	11.02	11.37	11.69	12.01	12.31	12.60	13.14	13.65	14.12	14.57	14.99
11,000	9.69	10.46	10.81	11.14	11.46	11.76	12.06	12.34	12.87	13.36	13.82	14.26	14.67
12,000	9.33	10.25	10.59	10.92	11.22	11.52	11.81	12.08	12.60	13.07	13.52	13.94	14.34
13,000	8.98	10.05	10.38	10.70	11.00	11.28	11.56	11.83	12.32	12.79	13.23	13.63	14.02
14,000	8.64	9.85	10.17	10.48	10.77	11.05	11.31	11.57	12.06	12.51	12.92	13.32	13.70
15,000	8.32	9.65	9.97	10.26	10.55	10.82	11.08	11.33	11.79	12.23	12.64	13.03	13.39

<sup>1</sup> Sullivan Machinery Co., Catalog.

**Air Lifts—Ratio of Lift to Submergence<sup>1</sup>**

Lift	Submergence
Up to 50 ft.	70-66 per cent.
50-100 ft.	66-55 per cent.
100-200 ft.	55-50 per cent.
200-300 ft.	50-43 per cent.
300-400 ft.	43-40 per cent.
400-500 ft.	40-33 per cent.

**METALLURGICAL CONSTRUCTION****Allowable Unit Strains For Metallurgical Works<sup>2</sup>****Substructure**

*Foundations.*—Pressure on foundations not to exceed, in tons per square foot:

Soft clay.....	2
Ordinary clay and dry sand mixed with clay. ....	3
Dry sand and dry clay .....	4
Hard clay and firm, coarse sand ..	6
Firm, coarse sand and gravel. ....	

*Masonry.*—Working pressure in masonry not to exceed, in tons per square foot:

Common brick, Rosendale-cement mortar.	10
Common brick, Portland-cement mortar ..	12
Hard-burned brick, Portland-cement mortar.	15
Rubble masonry, Rosendale-cement mortar	8
Rubble masonry, Portland-cement mortar.	10
Coursed rubble, Portland-cement mortar. ....	12
First-class masonry, sandstone.	20
First-class masonry, limestone	25
First-class masonry, granite .....	30
Concrete for walls:	
Portland cement 1-2-5	20
Portland cement 1-2-4	25

*Pressure on Wall-plates.*—The pressure of beams, girders, wall-plates, column bases, etc., on masonry shall not exceed the following, in pounds per square inch:

On brickwork with cement mortar. ....	200
On rubble masonry with cement mortar.	200
On Portland-cement concrete ..	350
On first-class sandstone...	400
On first-class limestone. ....	500
On first-class granite..	600

<sup>1</sup> Sullivan Machinery Co., Bull. No. 71-A.

<sup>2</sup> "Specifications for Structural Work on Buildings," A. S. M. E.

COSTS OF SOME METALLURGICAL PLANTS<sup>1</sup>

Character of plant	Capacity per 24 hours	Cost
Iron blast furnace.....	300 tons of pig iron....	\$650,000
Acid bessemer with four cupolas and hot-metal reservoir.	2000 tons of steel...	900,000
Acid open hearth, ten 50-ton furnaces.	1000 tons of steel . . . . .	1,500,000
Basic open hearth, ten 50-ton furnaces.	1000 tons of steel.. . . .	1,650,000
Rolling mill.. . . .	Starting with ingots 20 in. square, weighing about 5000 lb., consisting of 36-in. blooming mill and 28-in. structural mill.	1,250,000 to 1,500,000
Copper smelting and converting.	Partial pyritic smelting of 1000 tons of ore to 100 tons of 45 per cent. matte.	1,250,000
Lead smelting.....	500 tons of mixed lead ore.	250,000
Parkes desilverizing . . . . .	100 tons of lead bullion . .	250,000
Moebius electrolytic parting...	30,000 oz. of doré bullion .	20,000
Electrolytic copper refining, multiple process.	100 tons of copper, from pig to wire bars.	500,000
Zinc smelting . . . . .	100 tons of blende, not making sulphuric acid.	375,000
Stamp milling <sup>2</sup>	100 tons per day .	50,000
Cyaniding <sup>2</sup> .	100 tons per day. . . . .	100,000

<sup>1</sup> Hofman, "General Metallurgy," p. 888.

## Cost of Metallurgical Works

## Flotation Mill Costs

For a 500-ton flotation plant in the western part of the United States, making a two mineral separation, such as lead from zinc, the construction cost may be set down as approximately \$750 per ton of ore treated per day. Larger mills would cost less, and small ones might cost very much more.

## Sulphuric Acid Works

Sulphuric acid plant, to be added to zinc smeltery, cost in 1917, \$8 per ton of  $H_2SO_4$  per ton of annual capacity. As the ore usually contains about 32 per cent. S, the statement also applies per ton of ore.

## Effectiveness of Wood Preservatives

The relative efficiencies of certain widely used wood preservatives were recently tested by the U. S. Department of Agriculture (*Bull No. 227*).

The tests were made by the Petri-dish method. The quantities mentioned are sufficient to stop growth in a cubic foot of culture medium.

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For <i>Fomes annosus</i>	Pounds	For <i>Fomes pinicola</i>	Pounds
Coal-tar creosote:		Coal-tar creosote:	
Fraction II.....	0.14	Fraction III.....	0.08
Sodium fluoride.....	0.16	Fraction IV.....	0.08
Cresol calcium.....	0.09-0.18	Fraction II.....	0.09
Coal-tar creosote:		Sodium fluoride....	0.09
Fraction I.....	0.19	Wood creosote.....	0.13
Fraction III.....	0.20	Coal-tar creosote:	
Zinc chloride.....	0.31	Grade C.....	0.14
Coal-tar creosote, Grade C..	0.34	Fraction I.....	0.14
Water-gas tar distillate (sp.		Avenarius carbolineum	0.19
gr. 0.995).....	0.41	Zinc chloride.....	0.47
Wood creosote.....	0.41	Hardwood tar.....	0.47
Hardwood tar.....	0.78	Coal-tar creosote:	
Coal-tar creosote:		Fraction V.....	4.87
Fraction IV.....	2.06	Copperized oil.....	Over 25
S. P. F. carbolineum.....	2.8	United Gas Improve-	
Avenarius carbolineum..	3.27	ment Co., 1.07 oil.	Over 25
Coal-tar creosote:		Nonesuch special...	Over 25
Fraction V.....	20.59		
Copperized oil.....	25.0		
United Gas Improvement			
Co., 1.07 oil... ..	Over 25		
Nonesuch special .....	Over 25		
Sapwood antiseptic . . . .	Over 25		

ULTIMATE AND ELASTIC STRENGTHS OF MATERIALS<sup>1</sup>  
Metals (KIMBALL and BARR)

Material	Ultimate strength ( <i>U</i> )			Elastic strength ( <i>E. L.</i> )			Direct coefficient of elasticity ( <i>E</i> )	Transverse coefficient of elasticity ( <i>E<sub>t</sub></i> )
	Tension	Comp.	Shear	Tension	Comp.	Shear		
Cast iron . . . . .	20,000	95,000	20,000	10,000 <sup>1</sup>	25,000	8,000	15,000,000	6,000,000
Malleable iron . . . . .	35,000	42,000	20,000					
Wrought iron . . . . .	55,000		40,000	30,000	28,000	22,000	28,000,000	10,000,000
Steel, 0.15 carbon . . . . .	63,000		48,000	40,000	40,000		30,000,000	10,000,000
Steel, 0.50 carbon . . . . .	80,000		57,000	48,000	46,000		30,000,000	10,000,000
Steel, 0.70 carbon . . . . .	89,000		60,000	53,000	53,000		30,000,000	10,000,000
Steel, 0.80 carbon . . . . .	103,000		80,000	57,000	63,000		30,000,000	10,000,000
Steel, 0.96 carbon . . . . .	118,000		83,000	69,000	71,000		30,000,000	10,000,000
Steel, boiler plate . . . . .	60,000		48,000	30,000			30,000,000	
Crucible steel . . . . .	116,000			80,000	80,000		31,000,000	12,400,000
Steel castings . . . . .	50,000		40,000	30,000	30,000		25,000,000	
Nickel steel . . . . .	100,000			60,000			31,000,000	
Copper castings . . . . .	22,000	60,000		6,000			12,000,000	
Rolled copper . . . . .	31,000			6,000			15,000,000	
Brass castings . . . . .	20,000	12,000					10,000,000	
Bronze, gun metal . . . . .	35,000						12,000,000	
Bronze, phosphor . . . . .	50,000			20,000			14,000,000	
Tobin metal . . . . .	80,000			55,000				
Aluminum castings . . . . .	15,000	12,000	12,000	6,500	3,500		11,000,000	

<sup>1</sup> PIERCE and CARVER's, "Tables for Engineers" See also pp. 234, 602 and 603.

PROPERTIES OF VARIOUS METALS AND ALLOYS\*

Material	Tensile strength, lb. per sq. in.	Elongation in 2 in., per cent.	Compressive strength, lb. per sq. in.	Brinell hardness numeral	Melting point, deg. F.	Coef. of linear expansion per deg. F.
Cast iron.....	30,000	None	100,000	100	2000	0.0000068
Wrought iron.....	50,000	35	30,000	125	2760	0.0000066
Low-carbon steel, annealed....	60,000	35	40,000	...		
Low-carbon steel, cold rolled....	50,000	20	60,000	...		
Med.-carbon steel, annealed....	80,000	28	50,000	135		
Med.-carbon steel, heat treated	125,000	13	100,000	200	About	About
High-carbon steel, annealed....	86,000	33	...	156	2500	0.0000067-
High-carbon steel, heat treated..	200,000	10	...	375		
Alloy steel, heat treated.....	225,000	10	200,000	410		
Copper.....	35,000	50	...	42	1981	0.0000095
Cast red brass.....	30,000	22	30,000	40	....	0.0000105
Cast gun metal or govt. bronze	38,000	25	...	64		
Manganese bronze rolled	75,000	25	...	100		
Zinc.....	12,000	...	25,000	48	786	0.0000163
Aluminum	13,000	25	67,000	25	1218	0.0000130
No. 12 aluminum cast alloy.....	20,000	3	...	55		
Duralumin, rolled and heat treated	55,000	25	...	...	1200	
Tin.....	4,000	35	6,400	14	450	0.0000126
Lead.....	2,000	...	...	...	621	0.0000164
Genuine babbitt..	...	...	15,000	25	460	
Platinum.....	35,000	50	...	...	3191	0.0000050
Gold.....	30,000	25	...	...	1945	0.0000081
Silver.....	45,000	...	...	...	1765	0.0000108
Nickel.....	40,000	10	...	76	2646	0.0000071
Nichrome.....	150,000	...	...	...	2800	0.0000091
Manganin.....	120,000	...	...	...		
Constantan ..	70,000	25	...	...	2300	0.0000080
Stainless steel.						

\* Table by R. W. WOODWARD, Bur. Standards.

## PROPERTIES OF ALUMINUM AND ALUMINUM ALLOYS

Alloy	Composition	Tensile strength, lb.	Yield point, lb.
2S.....	Commercial Al	12,000-16,000	4,000- 7,000
3S.....	1.25 Mn	15,000-18,000	
17S (a).....	4% Cu; 0.5% Mn; 0.5% Mg	25,000-35,000	7,000-10,000
25S.....	4.5 Cu; 0.8 Mn; 0.8 Si	23,000-35,000	7,000-12,000
51S.....	0.6 Mg; 1.0 Si	14,000-19,000	4,000- 6,000
Spec. 17S.....	4 Cu; 0.6 Mn; 0.5 Mg; Si, 1.25	25,000-35,000	7,000-10,000
Y.....	4 Cu; 2 Ni; 1.5 Mg	30,000-40,000	25,000
17S (b).....	as above	55,000-63,000	30,000-40,000
25S (b).....	as above	55,000-63,000	30,000-40,000
51S (b).....	as above	45,000-50,000	30,000-40,000

(a) Duralumin.

(b) Heat treated, quenched and aged.

## CEMENT COMPOSITIONS

	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	NaKO
Portland <sup>1</sup> .	19-26	4-11	0-4	58-67	0-4	0-1.75	0-3
Rosendale <sup>1</sup> (natural)	27 30	7 14	1.80	35.98	18.00	.....	6 80
Slag cement <sup>1</sup> .	28.95	11.40	0 54	50.29	2.96	3.41	.....
Hydraulic <sup>2</sup> .	21.60	3 20	0.65	61.00	0.85	0.60	H <sub>2</sub> O = 12 00
Grenoble <sup>3</sup> natural <sup>2</sup>	26.30-27.30	9.30-12.70	..	50.80-55.00	0-3 00	.....	.....

<sup>1</sup> BENSON'S, "Industrial Chemistry," The Macmillan Company.<sup>2</sup> J. PARK, "Text-book of Practical Assaying."<sup>3</sup> Said to be finest natural cement in the world.STRENGTH OF COMMON MATERIALS<sup>1</sup>

Material	Ultimate strength (U)	
	Tension	Compression
Bricks, best hard.....	400	12,000
Bricks, light red.....	40	1,000
Brickwork, common.....	50	1,000
Brickwork, best.....	300	2,000
Cement, Portland, 1 month old.....	400	2,000
Cement, Portland, 1 year old.....	500	3,000
Concrete, Portland.....	200	1,000
Concrete, Portland, 1 year old..	400	2,000
Hemlock.....	6,000	4,000
Oak, white.....	10,000	7,000
Pine, shortleaf yellow.....	9,000	6,000
Pine, Georgia.....	12,000	8,000
Pine, white.....	7,000	5,500

<sup>1</sup> PIERCE and CARVER'S, "Tables for Engineers."

CEMENTS FOR EARTHWARE, CHEMICAL STONWARE AND FUSED SILICA

	No. 1	No. 2	No. 3	No. 4	No. 5
Kind of bond.....	Chemical and terra cotta stoneware	Chemical and terra cotta stoneware	Chemical stoneware and fused silica tower and bell-and-spigot joints	Chemical stoneware and fused silica tower and bell-and-spigot joints	Stoneware, glass and Duriron
Composition of cement.	Silex and sodium silicate solution 40 deg.	Silex and coal tar (or fire clay and tar)	Asbestos fiber, china clay, barium sulphate, melted pitch and coal tar	2 lb. caustic soda, 2 lb. water, 4 lb. linseed oil, 50 lb. silicate soda and 60 lb. china clay	Chemical Construction Co.
How made. ....	By mixing to the consistency of dough	By mixing to the consistency of dough	Mixed to a paste or molten sulphur	Mix first four ingredients in order, then boil and while hot stir in china clay	Proprietary
How applied. ....	By pressing into the joints	By pressing into the joints	Over asbestos rope	Troweled	As a paste
Application.....	Various mineral acids	Various mineral acids	Mineral acids; gases	.....	Acids
Suitable range of temperature.	Any range of temperature	Up to 200°F.	250°F.	0 to 150°F.	Up to about 200°F.

*Chem. and Met. Eng.*, June, 1927



The formula is as follows:

	Per cent.
Copper powder.....	83.8
Iron powder.....	8 4
Magnesium chloride.....	4.2
Magnesium oxide.....	2.5
Phosphoric anhydride....	0.8
Ammonium chloride.....	0.3

The finely powdered ingredients are mixed together in a ball mill and provided they do not become moistened, keep for a long time. When the cement is to be used it is mixed with about 5 per cent. by weight of water and then should be applied promptly. It sets thoroughly in a few hours. (1,468,930; assigned to the Stackpole Carbon Co.; Sept. 25, 1923.)

#### CEMENTS FOR METAL JOINTS

	No. 1	No. 2	No. 3	No. 4
Kind of bond	Iron to iron, iron to lead and lead to lead	Iron to iron, lead to lead and lead to iron	Glass and metal	Filling for holes and cracks in metal castings
Composition of cement	Red iron oxide free from silica, 5 parts and boiled linseed oil, 1 part	Red iron oxide, 2½ parts; barium sulphate, 2½ parts and boiled linseed oil, 1 part	Litharge and glycerine	Smooth On Mfg. Co.
How made	Mix oil into iron oxide	Mix oil into powder and to a thick dough	Mix to a thick cream	Proprietary
How applied	Paste		Brush	As directed
Application....	Hydrofluoric acid; sulphuric acid	Hydrofluoric acid; sulphuric acid	Steam and oil	Steam, oil and alkalis
Suitable range of temperature.	0 to 500° F.	0 to 500°F.	0 to 400°F.	

**Glue.**—While various grades require different amounts of water, in mixing a new and untried glue it is a safe rule to cover the broken glue with water and allow it to stand; if the glue while cold absorbs all the water, cover again and allow to stand. The glue should be allowed to absorb water for at least 2 hr. before melting. The old rule about using glue at the boiling point is wrong. It was shown conclusively during the War that the best temperature for use was 140°F. and that the glue should never be heated over 150°F. Glue which has been heated over 8 hr. is no longer first class and glue that has been melted, cooled, and remelted is not so strong as that which has only been melted once; therefore, small batches of glue are advisable. The wood should be dry and warm, and a glue room should be as warm and humid as working conditions will allow.

## SECTION X

### GENERAL METALLURGY

#### PROCESSES KNOWN BY THEIR INVENTORS' OR BY NON-DESCRIPTIVE NAMES

**Aczolling.**—The treatment of timber with a mixture of metallic ammoniates with an antiseptic acid (derivative of phenol or naphthalene).

**Augustin process** for silver extraction consists of chloridizing-roasting; leaching with hot solutions of common salt in wooden vats; precipitating the silver on copper and casting into silver bars; precipitating the copper on scrap iron and casting it into shot to be used again.

**Bessemer Process.**—The production of steel by blowing air through molten pig iron. Also, by analogy, the enrichment of copper matte by blowing air through it when molten. See *Converting*.

**Betts Lead Refining Process.**—An electrolytic process using  $\text{PbSiF}_6$  acidulated with  $\text{H}_2\text{SiF}_6$  as the electrolyte.

**Boss process** for silver extraction is a continuous pan-amalgamation process.

**Bradley Process for Manganese Recovery.**—Iron-manganese ore is leached with ammonium sulphate solution giving manganese sulphate and ammonia; the manganese is later precipitated with this same ammonia and the precipitate oxidized with air to fix it. To date, September, 1929, details of the process are extremely hazy.

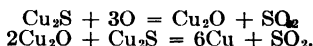
**Byers Process for Wrought Iron.**—The process was developed by Dr. JAMES ASHTON. Pig iron is melted in a cupola; refined in a converter and then poured into a bath of slag, the pouring and the gases liberated shocking the metal and covering the small particles with slag. The excess slag is poured off and the spongy mass remaining is passed through a blooming mill.

**Calorizing.**—A system of protecting metals against corrosion. The metal pieces to be protected are placed in a rotary retort and heated to a high temperature in a reducing atmosphere with a mixture containing aluminum. Calorized iron and steel is unaffected by sulphureted hydrogen, sulphur dioxide, sulphur vapor and the various gases and vapors of oil refinery practice.

Working results in a pressure-still drum cracking Mid-Continent crude were:

Material exposed 4 months	Loss in lb. per sq. ft. of surface
Calorized steel.....	0.013
Calorized steel.....	0.004
Steel plate.....	0.502
Steel plate.....	0.390
Tank steel.....	0.412
70-30 brass.....	0.128
70 Cu, 29 Zn, 1 Sn.....	0.090
60 Cu, 38.2 Zn, 1.2 Sn.....	0.056
Cupronickel, 36 Cu, 60 Ni, 4 Fe.....	1.204
Alloy No. 4.....	0.106
Alloy No. 9.....	0.170
Alloy No. 136.....	0.159

**Converting.**—The process invented by PIERRE MANHÉS in which air is blown through molten copper matte in the presence of free silica. The iron is oxidized to FeO which forms a slag with the silica; the sulphur is oxidized and goes off as SO<sub>2</sub>. After the iron is practically oxidized, copper is formed thus:



Also applied to the Bessemer process of steel manufacture.

**Coslettizing.**—A method of rust-proofing by means of phosphatic coatings. Ferrous phosphate was made by mixing iron filings with concentrated H<sub>3</sub>PO<sub>4</sub> sufficient to form a semi-fluid paste. This was added to weak boiling phosphoric acid. Iron or steel articles boiled in this for 3 or 4 hr. acquired a rust-resisting coating of basic ferrous phosphate. See also Parkerizing, p. 611.

**Diehl Process.**—A modification of the cyanide process in which cyanogen bromide is added to the leaching solution.

**Dumoulin Process.**—Copper is deposited on a rotating mandrel and this copper is later stripped off as a long strip, which is then drawn into wire without recasting.

**Elmore Process.**—A flotation process. See Flotation for full description.

**Estelle Process.**—An electrolytic-iron method based on its deposition from a suspension of its hydroxide in strong hot caustic soda.

**Eustis Process.**—Produces iron from pyrrhotite by dissolving the iron in ferric chloride solution and depositing the iron electrolytically. The sulphur is left as a residue which is filtered off and recovered.

**Gutzkow's Process.**—A modification of the sulphuric-acid parting process for bullion containing large amounts of copper. A large excess of acid is used; the silver sulphate is then reduced with charcoal or, in the original process, ferrous sulphate.

**Harris Process.**—Refining of lead by removal of arsenic, antimony and tin as sodium salts. The lead is treated while molten with air and molten sodium hydroxide.

**Hayden Process.**—For copper refining. There is but one true cathode and one anode in the tank, a large number of plates of unrefined copper being placed between and parallel to them. The side of each plate toward the cathode then acts as anode, while copper is deposited on the side of each plate toward the anode, until the entire plate has moved over by the amount of its own thickness. This is the so-called series method of refining.

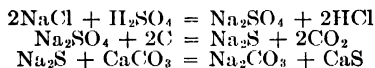
**Höpfner Process.**—Copper Recovery. A solution of cuprous chloride in sodium or calcium chloride is used to dissolve copper sulphides. The solution is then electrolyzed in tanks with diaphragms. The anodes are copper, the cathodes pure copper. Copper is deposited from the cuprous-chloride solution, and cupric chloride regenerated.

**Hunt's Process.**—Devised by Bertram Hunt for treating precious metal ores containing copper or zinc, using an ammoniacal cyanide solution and recovering ammonia by boiling. Process may more truly be said to have been devised and perfected by MOSHER.

**Hunt & Douglas Process.**—Consists in roasting matte carrying copper, lead, gold and silver at a very low temperature, forming copper sulphate and oxide but not silver sulphate. This product is leached with dilute sulphuric acid for copper. The resulting solution is treated with calcium chloride and the copper precipitated as subchloride by passing  $\text{SO}_2$  through the solution. The cuprous chloride was then reduced to cuprous oxide by milk of lime, regenerating calcium chloride, and the cuprous oxide was smelted.

**Kiss Process.**—About the same as the PATERA process (which see below) except that calcium hyposulphite was used for leaching the ore, and calcium polysulphide for precipitating the silver.

**LeBlanc process** for soda making



**Lohmannizing.**—A process by which a protective zinc coating is amalgamated to the base-metal sheet. Details of the process not made public.

**Luce-Rozan Process** (in Lead-refining).—A modification of the Pattinson process in which steam is used for stirring the molten lead, and the enriched lead is tapped out from the bottom of the kettles, leaving the impoverished crystals on a perforated plate.

**MacArthur-Forrest Cyanide Process.**—The original successful commercial process.

**Marriner Process.**—A modification of the cyanide process in which the ore is dead roasted, all of it ground to slime, and the resulting product treated by agitation.

**Miller process** of parting gold and silver by conducting chlorine gas into the molten metal. The silver and other base metals are chloridized and come to the top of the bath.

**Moebius Process.**—For parting gold and silver. The electrolyte is silver nitrate with a little nitric acid. In the original process the silver was deposited on an endless moving silver belt, from which it was constantly removed by revolving brushes.

**Murex Process.**—See under "Flotation," p. 505.

**Nitriding.**—A process of hardening steel with ammonia gas. The steels contain aluminum (about 1 per cent.), and preferably 1 per cent. Cr and 1 per cent. Mo and are exposed to ammonia gas at temperatures ranging from 950 to 1100°F. It should be noted that the aluminum is present as metal in the alloy. Nickeling to not less than 0.05 in. in thickness, or tinning is used to protect parts of the surface that are not be nitrided. Nitriding for 90 hr. produces a case hardening about 0.031 in. deep and will increase the BRINELL from 350 to 1,000.

**Norton Process.**—A method owned by the Aluminum Co. of America for the prevention of corrosion of light alloys.

**Parkes Process.**—Lead refining by the addition of zinc to molten argentiferous lead. The zinc and silver rise to the surface of the bath as a scum, which is then taken off and afterward distilled to drive off the zinc.

**Parkerizing.**—A modification of the Coslettizing process in which one fourth of the ferrous phosphate is oxidized to ferric phosphate by  $MnO_2$ .

**Patera process** consists in a chlorizing-roasting; leaching with water to remove base metals (some silver is dissolved and must be recovered); leaching with sodium hyposulphite for silver; precipitation of silver by sodium sulphide. The process was first carried out by VON PATERA at Joachimsthal.

**Patio process** is one for the recovery of silver by amalgamation in low heaps with the aid of salt and copper sulphate (*magistral*). Thorough mixing is obtained in the usual form by having horses or oxen tread the mass.

**Pattinson Process.**—Recovery of the silver from argentiferous lead by fractional crystallization of lead crystals out of a silver-lead eutectic. Seldom used now except in conjunction with the PARKES process (*q.v.*).

**Pierce-Smith Basic-converting Process.**—Converting copper matte in a magnesite-lined converter. The iron of the matte is fluxed by silica added before the process begins.

**Pelatan-Clerici process** is a continuous process of dissolving silver or gold in cyanide solution and simultaneously precipitating the precious metals in mercury in the same vessel, an electrical current assisting precipitation.

**Powellizing.**—A process of wood treatment consisting in impregnating the wood with a saccharin solution. It hardens the wood, and appears to fireproof it somewhat.

**Randolph Process.**—A modification of the series process of copper refining in which the electrodes lie horizontally, the top surface of each one acting as anode, the lower as cathode. Theoretically it has the advantage of extremely low metal

losses and great purity of copper. Practically, it is too difficult to right matters in a tank after a short circuit. See HAYDEN series and SMITH processes.

**Reese River Process.**—Pan amalgamation with previous roasting.

**Rozan Process** (LUCE-ROZAN process).—Pattinsonizing with steam.

**Russell Process.**—About the same as the PATERA (*q.v.*) except that cuprous-sodium hyposulphite is used in addition to the sodium hyposulphite.

**Series Copper-refining Process.**—See HAYDEN, SMITH and RANDOLPH processes.

**Sherardizing.**—A galvanizing process in which the metal to be coated is heated, with or without tumbling, in contact with zinc dust. Blue powder or manufactured dust may be used for the source of the zinc.

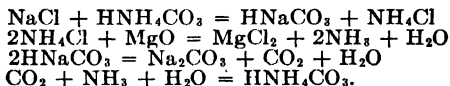
**Siemens & Halske Method of Copper Recovery.**—Copper sulphides are dissolved by solutions of ferric sulphate containing free sulphuric acid.

$(\text{H}_2\text{SO}_4) + \text{Cu}_2\text{S} + 2\text{Fe}_2(\text{SO}_4)_3 = 2\text{CuSO}_4 + 4\text{FeSO}_4 + (\text{H}_2\text{SO}_4)$   
The solution is then electrolyzed in a tank having a diaphragm. Copper is deposited and ferric sulphate regenerated.

**Siemens-Martin Process.**—The production of steel in a reverberatory furnace by oxidation of the impurities by oxides added (either the rust on scrap, or mill scale, or pure ores). It may be conducted either on an acid or a basic lining.

**Smith Process.**—A variation of the series system of copper refining in which the plates are placed horizontally, the top surface of each one acting as cathode, the lower as anode. Linen diaphragms must be placed between the plates to catch the slimes. These diaphragms break and allow the slimes to drop on the cathode, and it is impossible to remedy any short circuits in the tank without dismantling the tank.

**Solvay Process for Soda Manufacture.**



**Spellerizing.**—Subjecting the heated bloom to the action of rolls having regularly shaped projections on their working surface, then subjecting the bloom while still hot to the action of smooth-faced rolls. The surface working is said to give a dense texture to pipe made from the bloom, adapting it to resist corrosion.

**Thomas-Gilchrist Process.**—Bessemerizing (*q.v.*) pig iron high in phosphorus and low in S; in a converter lined with calcined dolomite. The slags formed consist of a basic calcium phosphate which is used for fertilizer.

**Thum-Balbach Process.**—A silver-refining process using carbon cathodes, doré anodes and a silver nitrate nitric-acid electrolyte. The silver is scraped off the bottom as crystals.

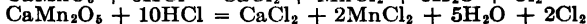
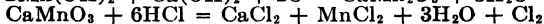
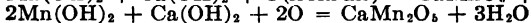
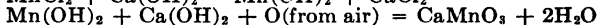
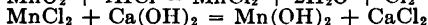
**Tredinnick Process.**—A modification of the Luce-Rozan process (*q.v.*) in which the kettles were mounted on hydraulic rams.

**Udylite Process.**—Rust-proofing by the electrolytic application of cadmium.

**Waelz Process.**—Residues or ores carrying lead and zinc are mixed with fuel and crushed, then fed into a kiln after preheating, the kiln being externally fired. The zinc is first reduced and volatilized, then burned and recovered in a Cottrell apparatus.

**Washoe Process for Silver Extraction.**—Consisted in wet crushing and pan amalgamation without previous roasting. Named for the district in which it was first carried on.

**Weldon's Process for Making Chlorine.**



**Wohlwill Process.**—A process of gold refining, using impure gold bullion as anodes and sheet gold cathodes in a solution carrying 25-30 oz. of gold and 25-30 oz. free HCl (sp. gr. 1.19) per cu. ft. If the anodes contain lead some  $\text{H}_2\text{SO}_4$  is added. The current density is about 100 amp. per sq. ft., the potential 1 volt. The tanks usually used are porcelain. Platinum and the allied metals remain in the electrolyte, the silver settles out as chloride.

**Z-D Process.**—One for prevention of corrosion of light alloys by coating the metal with an aqueous solution of sodium silicate, which is then baked on.

**Ziervogel Process.**—This consisted in smelting ore to an argentiferous matte; concentrating the matte to 60 or 70 per cent. Cu; grinding; roasting under such conditions of temperature control as to decompose the copper sulphate while leaving the silver sulphate undecomposed; leaching out the silver with water, precipitating the silver and recovering it; smelting the residues for copper bottoms from which the gold can be recovered.

### Alloys

In general, the thermal expansions of alloys do not differ greatly from the values calculated from the expansion coefficients and volume percentages of their constituents. The tendency is, however, for the change to be less than the calculated amount.

The electrical resistances of binary alloys are greater than the resistance of either constituent. The resistivity of a binary alloy is usually further increased by any third element entering into solid solution.

(Continued on p. 656)

## ALLOYS

	Cu	Zn	Sn	Pb	Sb	
Accumulator metal..	88 00		9.25	90.00	0.75	Condenser foil
Acid bronze	84 00		10.00	2.00		P, 0.20
Acid bronze	83 05		9.50	6.30		Recommended with acid mine-waters
Acid bronze	82 00	6 00	10.80	0.10		Mg 0.9, Fe 0.1, Si 0.4, bal Al
Acid bronze	82 00	8 00	2.00	8.00		Mg 0.98; Fe 0.94, Si 0.39; Mn 0.12; 91.87 Al
Acieral, cast	6.40	0 40	...	...		Mg 0.5, Fe 0.7; Mn 1.0; bal Al
Acieral, cast	5 70		...	...		Mg 0.1, Fe 1.4; Mn 1.5; bal Al
Acieral, sheet	3 80		...	...		Melts 1570°F
Acieral, sheet	2 30		...	...		Ni 29
Admiralty brass, A	70.00	29 00	1 00			Ni 44.3, Fe 0.5; Mn 1 15
Admiralty brass	61.70	36 90	1 40			Fe 0.5, Si 0.5; bal Al
Admic .....	70 00	...	1 00			Fe 1.3, Mn 0.14, Mg 2 1, bal Al
Advance	53 9	...	...			Fe 0.3; Si 0.4; Mg 2.9; bal Al
Aero metal, cast	4 2	27 8	...			See "German Silver"
Aero metal, sheet		0 6	...			Fe 1.50, high tensile, 85,000 lb. per sq. in.
Aero metal, sheet		0 2	...			Fe 30-70, Ni 50-52
Agroide			...			P 0.7
Aich's metal	60 00	38 12	...			Ni 1
Ajax bearing	5-20		...			Ni 18.75
Ajax phosphor bronze	79 30		10.00	10.00		See "German silver"
Ajax plastic	64.00		5.00	30.00		
Albatara ..	57.50	22 50	...	1.25		
Alfandide	...		...	...		
Algiers metal	5 0		94 50	...	0.50	
Algiers metal.			90.00	...	10.00	
Algiers metal			75.00	...	25.00	
Alkali-resisting			...	...	...	
Allan red bronze	62.50		7.50	30.00	...	
Allan red metal	50.00		50.00	...	...	
Alpakka	63.94	19 24	0 12	0.03	...	



Alloys Research.	3.00	20.00	Al 77
A forgings	2.50	20.00	Al 76: Mn 0.5; Mg 0.5; Fe 0.2; Si 0.2
E rolling	3.95	.....	Mg 0.5-1.1; Si 0.5-1.1; bal Al
25S.	4.00	.....	Al 92.5; Mg 1.5; Ni 2.0
Y casting	.....	.....	Al 2; Ni 94; Si 1; Fe 0.5; Mn 2.5
Alumel	.....	.....	Fe 0.4; Si 0.2; bal Al
Aluminate, cast	2.70	23.30	Al 77; Mg 11.5
Aluminum, hard	3.39	11.50	Al 93: Mg 1.39; Fe 1.46; Si 0.45
Aluminum, piston alloy	2.45	0.28	Al 93.5; Mg 1.47; Ni 1.47; Fe 0.4; Si 0.4
Aluminum, piston alloy	63.00	33.30	Al 33; Si 0.3—high Al
Aluminum brass	71.00	27.50	Al 1.25—low Al
Aluminum brass	88.40	.....	Al 97.4; Fe 0.43; Si 1.36
Al bronze, Cowles	92.50	.....	Al 7.5; Cowles C1, C2, C3, C4, Dare
Al bronze, Cowles B	98.75	.....	Al 1.25 / intermediate
Al bronze, Cowles E	81.50	.....	Al 7; Fe 4; Ni 5.5; Mn 2
Al bronze, French	90.00	.....	Cu 88.5-87; Al 7-9; Fe 2.5-4.5
Al bronze, Navy	.....	.....	Al 10.00
Al bronze, Percy	86.00	1.00	Al 12.5; Mn 0.5
Al bronze, Percy	89.43	0.38	Al 6.97; Fe 3.41
Al-iron bronze, H	85.16	.....	Al 6.6; Fe 7.52; Mn 0.5
Al-iron bronze, Reichs	85.15	.....	Al 9.43; Fe 4.74; P 0.09
Al-iron bronze, S	94.5	.....	Al 5.0
Al-Mg bronze	89.5	.....	Al 10.0
Al-Mg bronze.	89.12	.....	Al 9.6; Mn 1.2
Al-Mn bronze.	85.00	.....	Al 5-10; Ni 10-5
Al-Ni bronze.	85.50	2.00	Al 2.5
Al-tin bronze.	89.50	10.00	Al 10.50; Ti tr.
Al-titanium bronze.	.....	.....	Al 95.0; Ag 5.0
Aluminum silver	57.00	20.00	Ni 20.0; Al 3.0
Aluminum silver	5.50	.....	Al 84.2; P 0.1; "mock silver"
Al-copper, strongest	3.75	10.20	balance Al
Al-copper.	7.16	.....	Al 91.66; Fe 0.85; Si 0.33; melts 1160°C.
Al-copper	7.57	0.10	Al 91.62; Fe 0.43; Si 0.22; Mn 0.07

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Al-cupromagnesium.	3.63	..	..	..	..	Al 93.3; Mg 2.24; Fe 0.3-0.6; Si 0.3-0.4
Al-eupromagnesium.	3.37	..	..	..	..	Al 91.9; Mg 3.5; Fe 0.4; Si 0.3; Mn 0.55
Al-cupromagnesium.	4.00	..	..	..	..	Al 95.5; Mg 0.5; for casting
Al-eupro nickel.	2.00	..	..	..	..	Ni 5.25; bal Al
Al cupronickel.	4.10	..	..	..	..	Ni 1.1; bal Al
Al-Cu-Zn cast	5.00	15.00	..	..	..	Al 80.00
Al-Cu-Zn cast	3.00	22.00	..	..	..	Al 75.00
Al-Cu-Zn centrif. cast	3.00	17.00	..	..	..	Al 80.00
Al-Cu-Zn ingot.	3.15	12.80	0.12	0.19	..	Al 82.7; Mn 0.39; Fe 0.48
Al-Cu-Zn ingot.	5.52	9.90	0.27	0.30	..	Al 82.8; Mn 0.18; Fe 0.81
Al-Cu-Zn ingot.	4.87	11.10	..	..	..	Al 83.55; Mn 0.06; Fe 0.19; Si 0.27
Al-Ni-Ti.	..	..	..	..	..	Al 97.5; Ni 2.0; Ti 0.4
Al-Ni-Zn.	..	5.0	..	..	..	Al 85.0; Ni 10.0
Al-Va alloy.	5.01	13.7	..	..	..	Al 80.2; Fe 0.72; V 0.2
Al-W alloy	12.32	4.5	..	..	..	Al 82.1; W 1.0
Aluminum solder.	..	66.60	50.00	33.30	..	Figures are parts, not per cent.
Aluminum solder.	..	..	47.50	47.50	..	Ca 5
Aluminum solder.	..	30.00	65.00	..	..	Bi 5.0
Aluminum solder	8.00	80.00	..	..	..	Al 12.0
Aluminum solder	..	57.00	..	..	..	Cd 43.0
Aluminum solder	1.10	20.31	49.50	26.06	3.43	Al 10; PSn 5
Aluminum solder	..	..	85.0	..	..	Al 18.18
Al solder, Bourbouse.	..	81.82	..	..	..	Al 3.0
Al solder, Burgess	..	21.00	76.00	..	..	..
Al solder, Cornade and Cruijs	..	52.00	30.00	..	..	Al 17.5; Ni 0.5
Al solder, Frismuth	5.50	47.50	31.50	..	..	Al 10.5; Ag 5.5
Al solder, Frismuth	5.30	47.40	36.80	..	..	Al 10.5
Al solder, Frismuth.	..	..	67.00	27.00	..	Al 3.0
Al solder, Grimm's	..	1.44	69.10	28.80	..	Ag 0.72
Al solder, Grimm's.	..	25.00	50.00	25.00	..	..

Al solder, Mourey's	2.00	94.00	.....	.....	Al 4.0
Al solder, Mourey's	8.00	80.00	.....	.....	Al 12.0
Al solder, Richards	.....	25.00	.....	71.50	Al 3.5
Al solder, Wagner and Guhr's	.....	20.00	.....	80.00	Bi 14.0
Al solder, Wilmott's	.....	.....	.....	86.00	P 0.3
Anax metal	81.30	.....	.....	11.00	.....
Ambrac.	74.50	5.00	.....	7.40	.....
American silver	49.36	20.70	.....	0.45	Ni 20.0; Mn 0.5
American silver	57.70	24.20	.....	0.69	Ni 24.2; Fe 1.3; Mn 3.83; Al 0.13
American silver	59.11	22.66	.....	1.50	Ni 15.3; Fe 0.6
Ampco	bal	.....	.....	2.90	Ni 11.22; Al 1.5, PSn 5.0
Anatomical alloy.	.....	.....	.....	19.00	Al 7-11; Fe 8, Melts 995°C.
Antifriction	.....	.....	.....	17.00	Bi 53.5; Hg 10.5; fuses 60°C.
Antifriction	0.50	.....	.....	10.00	Pb 84-88, Sb 16-12
Antifriction	1.00	.....	.....	77.00	See also "bearing metal"
Antifriction	.....	20.00	.....	8.00	See also "bearing metal"
Antifriction	.....	1.00	.....	20.00	Fe 0.6
Anvil brass	62.50	37.50	.....	78.80	.....
Apbit (aphtit)	70.00	5.50	.....	.....	.....
Apbit	75.10	2.37	.....	.....	Ni 20.0; Cd 4.5
Arce's Tombac	82.30	17.70	.....	.....	Ni 20.75; Cd 1.8
Arce's French metal	50.00	30.00	.....	.....	.....
Argental	85.00	.....	.....	10.00	Ni 20.0
Argentan	56.00	18.00	.....	.....	Co 5.00
Argentan, Berlin casting	48.32	23.80	.....	.....	Ni 26.0; resistance alloy
Argent., Berlin sheet	55.50	29.10	.....	.....	.....
Argent., Chinese	40.40	25.40	.....	.....	Ni 24.15; Fe 3.61; see also "German silver"
Argent., English	63.36	17.01	.....	.....	Ni 15.5
Argent., French	50.32	30.94	.....	.....	Ni 31.6; Fe 2.6
Argent., Russian cast	57.52	18.94	.....	.....	Ni 19.13; Fe 0.38
Argent., Russian sheet	63.88	17.58	.....	.....	Ni 18.4
Argent., Vienna	55.60	21.80	.....	0.32	Ni 20.35; Fe 3.15
Argent., solder	35.00	57.00	.....	.....	Ni 17.58; Fe 0.33
Argent., Mousset's	59.50	9.50	.....	.....	Ni 22.2; Fe 0.38
			.....	.....	Ni 8
			.....	.....	Ni 3.5; Ag 27.5

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Argentan, Française, Roule	42.5	15 75	85 00	2 00	14 50	Cu 35-50; Ni 30-25; Ag 40-20
Argent, Française, Odessa	0.50	28 00	2 00	3 54	14 50	Ni 8 5; Ag 33 25
Argentin	54.00	23 00	4 03	3 54	14 50	Ni 13 4
Argosil bronze	55 78	31 00	4 03	3 54	14 50	Ni 20 5
Arguzoid	48 50	31 00	4 03	3 54	14 50	See "German silver"
Arguzoid, Birmingham	48 50	31 00	4 03	3 54	14 50	Cr 12, Co .45, bal Fe, heat-resisting
Argyrolith	80 00	20 00	85 00	2 00	14 50	Ag 0 8
Arko brass	79 70	1 50	79 50	19 40	14 50	Ni 2
Armstrong	2 50	1 50	79 50	19 40	14 50	Or Zn 2 80 replacing Cu
Arsenic bronze	2 50	1 50	79 50	19 40	14 50	Ni 13 92; Mn 0 23, Al 0 17
Ashberry metal	2 50	1 50	79 50	19 40	14 50	Ni 12 36; Mn 0 16
Ashberry Britannia	2 50	1 50	79 50	19 40	14 50	Ni 10 82; Mn 2 24
Aterite cast	66 75	17 25	88 00	5 00	3 00	See also "Bearing metal"
Aterite, rolled	67 76	19 97	88 00	5 00	3 00	See also "Bearing metal"
Aterite, rolled	46 96	38 00	90 00	5 60	7 40	See also "Bearing metal"
Augsburg brass	71 90	27 60	84 00	5 60	7 40	See also "Bearing metal"
Babbitt, original	4 00	69 00	19 00	5 00	3 00	Cr 4 25; Ni 90 0, W 1 2; Si 0 3
Babbitt, hard	8 00	69 00	19 00	5 00	3 00	Cr 20 00; Co 60 0, W 20 0
Babbitt, marine	3 00	69 00	19 00	5 00	3 00	Cr 30 00; Co 30 0, W 25 0; Mn 10; Ti 5
Babbitt, normal	3 00	69 00	19 00	5 00	3 00	
Babbitt, soft	3 00	69 00	19 00	5 00	3 00	
Baro, sheet	3 00	69 00	19 00	5 00	3 00	
Baro, hard	55 00	45 00	21 30	12 00	6 00	
Baro, soft	83 00	17 00	21 30	12 00	6 00	
Bath metal	83 00	17 00	21 30	12 00	6 00	
Bath metal	83 00	17 00	21 30	12 00	6 00	
Battery plates	3 20	63 40	21 30	12 00	6 00	
Battery plates	3 20	63 40	21 30	12 00	6 00	

	94 00	6 00	
Battery coppers			
Bearing metal			1.00 86.00 13.00
Bearing, . . .	0 08		8.30 83.30 8.30
Bearing, . . .			2.00 82.00 16.00
Bearing, . . .	0 50		11.60 80.50 7.40
Bearing, . . .			10.00 80.00 10.00
Bearing, <i>Cte de l'Est</i>			12.00 80.00 8.00
Bearing metal, . . .			5.00 80.00 15.00
Bearing, Katzenstein	0 40		7.30 75.60 16.80
Bearing, . . .			7.00 76.00 17.00
Bearing, French auto			10.00 75.00 15.00
Bearing, Am Ry			8.00 73.50 18.50
Bearing, Am. Ry	0 40		8.50 73.00 18.00
Bearing, . . .	2 00		7.70 71.80 18.50
Bearing, French Ry			20.00 70.00 10.00
Bearing, P-L-M. Ry			10.00 70.00 20.00
Bearing, . . .	1.60		9.60 68.00 20.50
Bearing, Am Ry			21.00 68.00 11.00
Bearing, . . .			15.00 68.00 17.00
Bearing, graphite metal			28.20 62.50 10.00
Bearing, . . .	1.30		27.00 62.00 10.00
Bearing, Jacoby metal			35.00 61.0 13.00
Bearing, . . .	1.00		20.00 60.00 20.00
Bearing, . . .			42.00 42.00 16.00
Bearing, Est Ry..			40.00 48.00 10.00
Bearing, . . .	2.00		36.50 46.00 16.50
Bearing, Am . . .	1.00		1.50 . . . . . 1.50
Bearing, hard . . .	7.00	90 00	2.00 . . . . . 2.00
Bearing, . . .	8.00	88 00	
Bearing, . . .	5.00	85 00	
Bearing, . . .	5.50	77 00	17.50
Bearing, . . .			
Bearing, English.	7 40	67 70	14.90
Bearing, . . .	4 20	66.50	29.30
Bearing, . . .	0 35	55 00	22.70
Bearing, heavy . . .	1.00	47 00	38.00 4.00
			1 25 . . . . . 6.00
			Al 20.0
			Also 2 42:40:16
			Also 1:50:37 12

Alloys. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Bearing, Krupps.....	8.00	.....	5.00	.....	.....	Al 87.0
Bearing, Navy.....	4.50	.....	91.00	.....	4.50	
Bearing, Prussian.....	3.00	.....	91.00	.....	6.00	
Bearing, Russian.....	4.00	.....	90.00	.....	6.00	
Bearing, English R R.....	3.00	.....	90.00	.....	7.00	
Bearing, Russian Ry.....	2.00	.....	90.00	.....	8.00	
Bearing, Am. auto.....	1.80	.....	89.30	.....	8.90	
Bearing, Am. auto.....	4.00	.....	89.00	.....	7.00	
Bearing, Navy.....	3.70	.....	89.00	.....	7.30	
Bearing, Am. auto.....	6.00	.....	87.00	.....	7.00	
Bearing, heavy.....	7.50	.....	85.00	.....	7.50	
Bearing, French car.....	5.50	.....	83.30	.....	11.10	
Bearing, Germ. Ry.....	6.00	.....	83.00	.....	11.00	
Bearing, Valve rods.....	8.00	.....	82.00	.....	10.00	
Bearing, French Ry.....	6.00	.....	82.00	.....	12.00	
Bearing, piston.....	6.50	.....	81.00	.....	12.50	
Bearing, Swiss Ry.....	10.00	.....	80.00	.....	10.00	
Bearing, English.....	7.80	.....	76.70	.....	15.50	
Bearing, German.....	7.00	.....	76.00	.....	17.00	Also with 3 Cu replacing 3 Sb
Bearing.....	10.00	.....	75.00	.....	15.00	
Bearing, Prussian.....	11.00	.....	74.00	.....	15.00	
Bearing, Prussian.....	9.00	.....	73.00	.....	18.00	
Bearing, Prussian.....	2.00	.....	72.00	.....	26.00	
Bearing, Ger. Ludenscheldt.....	3.85	.....	71.80	.....	24.30	
Bearing, Kamarsch.....	21.40	.....	71.40	.....	7.20	
Bearing, valve packing.....	5.00	.....	71.00	.....	24.00	
Bearing, German.....	4.90	.....	70.80	9.20	15.10	Also 4.7:74:11.8:9.5
Bearing, Kamarsch.....	9.50	.....	70.70	.....	19.70	
Bearing, G. W. Ry.....	22.00	.....	67.00	.....	11.00	
Bearing, French Ry.....	11.00	.....	67.00	.....	22.00	

Bearing.....	2 80	.....	61.00	25.50	10.50	
Bearing.....		.....	45.00	40.00	15.00	
Bearing.....		.....	38.00	37.00	25.00	
Bearing, E. D. B. Berlin.	90.00	.....	10.00	.....	.....	Also Cu 90; Zn 7; Sn 3
Bearing, locomotive.	89.00	7.80	2.40	.....	.....	Fe 0.8
Bearing, E. D. B. Breslau.	88.00	2.00	5.00	.....	.....	P Sn 5.00
Bearing, auto.	88.00	.....	8.00	3.00	.....	P Sn 1.00
Bearing, hard Ry. axle	87.05	5.07	7.88	.....	.....	Also 88.8:2.7:8.5
Bearing, Rhineland Ry.	86.00	2.00	12.00	.....	.....	Mn 2.70
Bearing.....	86.60	5.00	6.00	.....	.....	Also 85.5:1.7:12.8
Bearing, Dutch loco.	85.25	2.00	12.75	.....	.....	
Bearing.....	85.00	4.00	11.00	.....	.....	
Bearing.....	84.00	.....	8.00	8.00	.....	Also 80:5:15
Bearing, Prussian Ry.	84.00	1.00	15.00	.....	.....	Also 82:18
Bearing, Am. cars	84.00	.....	16.00	.....	.....	Also 83:5:12 and 83.7:2.10:14.20
Bearing, Am. Ry.	83.70	7.50	8.80	.....	.....	Also 78:2:20
Bearing, Am. Ry.	83.00	2.00	14.00	1.00	.....	
Bearings, French Ry. cars	82.00	8.00	10.00	.....	.....	Fe 0.9
Bearing, German loco	81.17	15.20	.....	14.60	.....	Also 84:14:2 and 80:7:3
Bearing, autos...	81.00	3.00	7.00	9.00	.....	P Sn 2.0
Bearing, Lefond's	80.00	2.00	18.00	.....	2.00	Stephenson's is 79.5:5:7.5:8
Bearing, Belgian Ry.	80.00	.....	16.00	2.00	.....	Dudley's "K" is 77:10.5:12.5
Bearing, auto.	80.00	.....	10.00	8.00	.....	P Sn 1.0
Bearing, engines.....	79.00	5.00	8.00	8.00	.....	Dudley's "B" is 77:15:8
Bearing, Ry. car.	78.00	.....	7.00	15.00	.....	Cheap
Bearing, auto.	78.00	1.00	8.00	12.00	.....	
Bearing, auto.....	77.00	14.00	9.00	.....	.....	Also 74:9:10:7
Bearing, Russian cars	77.00	5.10	10.20	7.70	.....	Fe 0.5
Bearing, Daimler	76.00	20.00	3.00	1.00	.....	
Bearing.....	75.00	21.00	4.00	.....	.....	
Bearing, Am. cars	75.00	5.00	20.00	.....	.....	
Bearing, locomotive	74.50	8.90	9.50	7.10	.....	
Bearing, loco. durable.	73.50	9.50	9.50	7.50	.....	
Bearing, loco. piston.	74.10	22.20	3.70	.....	.....	

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Bearing	72 40	29 90	4 70	1 50	....	Cheap
Bearings, Bersch's	....	....	....	....	....	Al 93 0; Ni 7
Bell metal	....	....	....	....	....	Al 83 0; Mn 10 00; Cd 7
Bell metal, musical	54 00	....	16 00	....	....	
Bell, 300 yr. old	80 00	....	20 00	....	....	
Bell, "best"	78 00	....	22 00	....	....	
Bell, 600 yr. old	76 20	....	23 80	....	....	
Bell, clock	75 00	....	25 00	....	....	
Bell, Darmstadt, old	73 94	....	21 67	2 11	....	Fe 0 19; Ni 2 0
Bell, Darmstadt, old	72 52	....	21 06	2 14	....	Fe 0 05; Ni 2 68
Bell, Harbohn	71 43	2 70	26 40	....	....	
Bell, Harbohn	60 00	5 00	35 00	....	....	
Bell, Rouen, old	71 00	1 80	26 00	1 20	....	
Bell, Karakane	71 42	....	14 20	14 30	....	
Bell, Karakane	70 00	3 00	19 00	8 00	....	
Bell, Karakane	65 95	3 45	17 25	10 35	....	
Bell, Karakane	64 00	9 00	24 00	....	....	Fe 3 0
Bell, Karakane	62 50	9 40	25 00	....	....	Fe 3 1
Bell, Karakane	61 00	6 00	18 00	12 00	....	Fe 3 0
Bell brass	64 25	35 00	0 75	....	....	Gong metal Cu 78; Zn 22
Benedict plate	57 00	28 00	....	....	....	Ni 15 0
Benedict metal.	....	....	....	....	....	Cu 84-86; Ni 16-14
Berlin alloy	52-63	26-31	....	....	....	Ni 22-6
Biddery metal	6 30	90 20	0 80	2 60	....	Also 48 5:33 32:6 06:12 15
Biddery, Henie's.	11 40	84 30	1 40	2 90	....	
Bilgen bronze..	97 32	....	1 89	0 24	....	
Binding-post brass.	63 25	35 00	....	1 75	....	
Birmingham nickel-silver, best	50 00	29 00	....	....	....	Ni 21 0
Brn. ni silver, first	56 00	27 00	....	....	....	Ni 17 0 or 56:28:16
Brn. ni silver, second	62 00	24 00	....	....	....	Ni 14 0



Brm. m. silver, third.	56 00	32 00	Ni 12.0 also 56.5:32.5:11
Brm. m. silver, fourth	55 00	35 00	Ni 10 0
Brm. m. silver, for plate	57 00	36 00	Ni 7.0
Brm. Ni silver, white	54 00	22 00	Ni 24 0
Brm. Ni silver, ex wht	50 00	20 00	Ni 30 0
Birmingham platina	20 25	79 40	Fe 0.33
Birmingham platina	46 60	53 15	Fe 0.25
Bismuth brass	52 00	12 00	Ni 30 0; Bi 1
Bismuth	47 00	21 00	Ni 30 9, Bi 0 1
Bismuth bronze	53 00	20 00	Ni 10, Al 1, Bi 1
Bismuth bronze	45 00	21 50	Ni 32 50; Bi 1
Bismuth solder	..	..	Bi 40 0 also 33 3 each
Bismuth solder	80 00	..	Bi 27 5 also 50:25:25
Blanko-Blech	77 00	..	Ni 20 0
Blatt gold	..	..	Fe 0 23
Blatt silver	..	23 00	Also 66:34
Bobierre metal	58 20	41 70	Cr 30, Co 35; Ni 35
Borcher's non-corrosive	..	..	Cr 30, Co 34; Ni 34; Ag <sup>2</sup>
Borcher's non-corrosive	..	..	Cr 30, Co 35; Ni 35 with Mo 0.5-5
Borcher's non-corrosive	..	..	Cr 36; Fe 60; Mo 4
Borcher's non-corrosive.	..	..	Cr 65; Fe 35
Bourbonne's metal	0 25	..	Al 48 8; Fe 0 33
Brass, ordinary.	65 00	35 00	Also called "buckle brass"
Brass, high	61 50	38 50	Rich low brass 85:15
Brass, low	80 00	20 00	Melts at 1780°F
Brass, red	85 00	5 00	Also used for brush wire
Brass, bell	64 25	35 00	..
Brass, block	66 50	32 00	..
Brass, byw-wire.	93 00	2 00	..
Brass, brazing	75 00	25 00	..
Brass, brazing F	85 00	15 00	..
Brass, bronze powder	84 00	16 00	..
Brass, Goulet	90 90	9 00	..
	..	1 00	"Medal metal"

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Brass, burr metal.....	90.00	10.00	.....	.....	.....	"Commercial bronze"
Brass, butt .....	65.50	33.50	.....	1.00	.....	Also 63.5:35.5:1
Brass, button.....	89.50	10.00	0.50	.....	.....	See "Biddery" p. 622.
Brass, button.....	43.00	57.00	.....	.....	.....	Forbes metal 45.5:53.5
Brass, button, Bristol .....	61.12	36.11	2.77	.....	.....	Also 57.9:36.8:5.3
Brass, button, gold .....	58.71	33.03	5.50	2.75	.....	See "Guettier's metal"
Brass, button, Jackson's.....	63.88	30.55	5.55	.....	.....	Also 63.0:35.6:1.40
Brass, button, Ludenschmidt .....	20.00	80.00	.....	.....	.....	Also Cu 93: Zn 7
Brass, cap gilding .....	89.75	9.87	.....	0.38	.....	Also 68:32 and 70:30
Brass, cartridge .....	66.67	33.33	.....	.....	.....	"Commercial" 63:37
Brass, check .....	62.00	38.00	.....	.....	.....	
Brass, clock .....	62.50	35.75	.....	1.75	.....	
Brass, collet.....	61.00	36.50	.....	2.50	.....	
Brass, com'l. casting .....	62.00	30.00	6.00	2.00	.....	
Brass, cymbal .....	78.00	22.00	.....	.....	.....	
Brass, diaphragm.....	95.00	2.00	3.00	.....	.....	
Brass, door plate .....	63.00	35.00	.....	2.00	.....	
Brass, drawing .....	66.67	33.33	.....	.....	.....	Deep drawing 70:30
Brass, drill rod .....	62.00	35.50	.....	2.50	.....	
Brass, electrical castings .....	84.00	13.00	3.00	.....	.....	
Brass, English .....	70.30	29.30	0.17	0.26	.....	
Brass, engravers .....	66.00	33.00	.....	1.00	.....	
Brass, escutcheon pin.....	64.50	35.07	.....	0.43	.....	
Brass, eyelet.....	68.00	32.00	.....	.....	.....	
Brass, fan blades .....	61.50	37.00	.....	1.50	.....	
Brass, flush plate .....	65.75	32.75	.....	1.50	.....	
Brass, fob metal.....	87.50	12.00	0.50	.....	.....	
Brass; forgings.....	60.00	40.00	.....	.....	.....	Also 57:43
Brass; forging, Russian .....	53.50	42.00	.....	.....	.....	Mn 4.5
Brass, fourdrinier wire .....	84.63	15.00	0.37	.....	.....	Also Cu 80; Zn 20

Brass, free cutting	88.50	10.00	1.50	"Commercial bronze" "lead bronze"
Brass, gold leaf	70.00	30.00	.....	See "Gold leaf"
Brass, grommet	88.00	12.00	.....	"Helmet bronze"
Brass, hardware	88.00	9.50	1.50	"Hard ware bronze"
Brass, helmet	72.27	27.58	0.09	Fe 0.04
Brass, jeweler's	91.50	6.50	2.00	Also 91:7.5:1.5 and 83:17:0
Brass, jeweler's	88.00	11.25	0.75	Also 87.5:12:0.5
Brass, journal box	92.50	7.50	.....	
Brass, kick plate	84.00	15.00	1.00	
Brass, machinery	83.00	16.00	1.00	
Brass, manganese	.....	.....	.....	See "Manganese brass"
Brass, matrix	62.00	36.50	1.50	
Brass, naval N-C	61.00	38.00	1.00	
Brass, pen metal	85.00	13.00	2.00	
Brass, percussion cap	93.00	5.00	.....	
Brass, pin wire	61.00	31.00	.....	
Brass, primer gilding	97.00	3.00	.....	
Brass, reed	69.00	30.00	1.00	
Brass, rule	62.50	35.00	2.50	
Brass, Russian cast	78.00	21.00	1.00	
Brass, screen plates	58.00	41.00	0.75	0.25
Brass, screw	78.00	16.00	4.50	1.50
Brass, screw	62.00	38.00	.....	Also 93:5:1:0.5 "Screw bronze"
Brass screw	69.00	29.50	1.50	
Brass, sheet, Chinese	56.60	38.20	3.30	Fe 1.4
Br., sheet, Hegermuhl	72.16	27.45	0.20	Also 62:370.5:0.5
Br., sheet, Hegermuhl	72.00	27.00	1.00	Also 62:3:1
Br., sheet, Iserlohn	70.10	29.90	.....	7:
Br., sheet, Jamappes	64.60	33.70	0.20	1.40
Br., sheet, Japanese	66.60	33.40	.....	
Br., sheet, Oker	69.00	29.50	0.97	
Br., sheet, Oker	55.00	44.50	0.50	
Br., sheet, Romilly	70.10	29.26	0.17	0.28

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Br., sheet, Rosthorn Wln	68.10	31.90	0.40	2.00		
Br., sheet, Stollberg	64.80	32.80				
Brass, shell-head	75.00	25.00				
Brass, shoe nail	63.00	37.00				Also 66.67:33.33
Brass, spring	72.00	28.00	1.00			
Brass, tubes, admiralty	70.00	29.00				
Brass, tubes, German	70.00	30.00				This is "Cuivre poli"
Brass, tubes, English	65.00	35.00				Also 61.5:38.5
Brass, tubes, Russian	59.72	38.62	0.16	0.34		Fe 1.1; also 66:34
Brass, turbine	75.77	24.07				
Brass, turbine	67.35	32.02		0.23		Fe 0.38
Brass, valve	90.00	6.00		4.00		Must stand peening and hammering
Brass, washer	62.00	38.00				Also 60:40
Brass, wheel	68.00	30.00		2.00		
Brass, wire, common	65.40	35.60				
Brass, wire, English	70.29	29.36	0.28	0.17		
Brass, wire, German	71.89	27.33		0.85		
Brass, solder, hard	57.00	43.00				Also 50:50
Brass, solder, white	40.00	60.00				
Br. solder, white, soft	44.00	49.90	3.30	1.20		Thurston
Br. solder, wht. very soft	57.44	27.98	14.58			Thurston
Br. solder, yellow, hard	53.30	43.10	1.30	0.30		Thurston
Bristol brass	75.70	24.30				Also 67.2:32.8; and 60.8:39.2
Britannia, English	1.00		94.00		5.00	
Britannia, spinning	2.60		93.70		3.75	
Britannia (Tutania)	2.45		92.35	0.32	4.65	
Britannia, sheet	1.40		91.50		7.10	
Britannia (Tutania)	0.70	0.25	91.40	7.62		
Britannia, casting	0.20		90.60		9.20	
Britannia, plate	1.46		90.62		7.81	

Brit., Birmingham I.	0.03	1.30	90.57	9.38	
Britannia (Tutana)	2.70	1.30	90.00	6.00	B 2.00
Britannia, English	2.00	...	90.00	7.00	
Britannia, English	3.00	...	90.00	7.10	
Brit., (Queen's Metal)	3.48	...	88.52	8.68	Also 0.15:85 5:14.4
Britannia, spoons...	2.80	...	88.42		
Britannia, spoons	3.68	1.53	84.46	5.62	Bi 4 88
Brit. Birmingham II.	1.00	3.00	85.50	10.50	Also 18:3 0:85.5:9.7
Britannia, German	2.00	5.00	84.00	9.00	
Britannia, German	1.80	...	81.90	16.30	
Brit., Ludenscheidt.	3.85	...	71.85	24.26	
Britannia, German	4.91	...	70.82	15.10	
Britannia, casting.	3.00	47.50	47.50	1.00	Cr 15-20; Ni 60-75; Si 4; W 1-4; Al 2; Mn 3;
Brit.	5.0	...	...	...	Ti 3; B 1; non corrosive
Bronze, bearing.	74.40	8.90	9.50	7.10	See "Bearings" p 619.
Bronze, brass	70.00	10.00	10.00	10.00	
Bronze, bridge A	80.00	...	20.00	...	P 0.1
Bronze, bridge B	85.00	...	15.00	...	P 0-1
Bronze, bridge C	80.00	...	10.00	10.00	P 0.7-1.0
Bronze, bridge D	88.00	2.00	10.00	...	P 0.25 Gear metal
Bronze, bushing	86.20	3.60	10.20	...	Also used for cogs, worms
Bronze, bushings	85.00	4.00	11.00	...	
Bronze, carbon	75.47	...	9.72	14.57	C 0.24
Bronze, Chinese	74.00	10.00	1.00	15.00	Also 74:10:1:15
Bronze, Chinese art.	72.50	14.30	4.70	18.50	
Bronze, cocks	88.00	2-6	10-8	...	British coinage
Bronze, coinage	95.00	1.00	4.00	...	P 0.8
Bronze, Cornish	77.8	...	9.6	12.6	"Damar bronze"
Bronze, Damascus	77.00	...	10.50	12.50	
Bronze, eccentric rings	84.00	2.00	14.00	...	
Bronze, flange metal, Fr	94.35	...	5.60	0.05	
Bronze, flange metal, Ger	92.40	...	2.50	5.05	

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Bronze, gear.....	91.30	2.00	8.70	.....	.....	Stone's is 89:11
Bronze, gear.....	85.00	3.00	10.00	2.00	.....	See "Gun metal"
Bronze, gun metal.....	80.00	17.00	3.00	.....	.....	
Bronze, high temperature.....	90.70	6.30	2.70	1.30	.....	
Bronze, hydraulic.....	83.00	6.00	10.80	0.01	.....	
Bronze, hydraulic.....	78.00	10.00	12.00	.....	.....	
Bronze, injector.....	84.00	5.00	8.50	2.50	.....	
Bronze, instrument.....	82.00	1.00	13.00	.....	.....	
Bronze, Japanese art.....	82.70	1.80	.....	4.70	.....	Also 71.4:6:5.9
Bronze, Lafonds.....	.....	.....	.....	.....	.....	See "Bronze, whistle," p. 629
Bronze, leaded.....	80.00	.....	10.00	10.00	.....	Melts at 1735°F.
Bronze, manganese.....	.....	.....	.....	.....	.....	See "Manganese bronze"
Bronze, medal.....	92.00	.....	8.00	.....	.....	
Bronze, medal.....	97.00	2.00	1.00	.....	.....	
Bronze, oil cup.....	88.00	7.00	5.00	.....	.....	P3
Bronze, oil pump.....	83.00	9.00	3.00	.....	.....	
Bronze, ormolu.....	.....	.....	.....	.....	.....	See "Ormolu," p. 646
Bronze, phosphor.....	.....	.....	.....	.....	.....	See "Phosphor bronze"
Bronze, piston.....	83.00	16.00	1.00	.....	.....	
Bronze, piston ring.....	84.00	8.30	2.90	4.30	.....	
Bronze, screw nut.....	86.00	2.30	11.40	.....	.....	
Bronze, sheet.....	90.00	.....	10.00	.....	.....	
Bronze, silicon.....	.....	.....	.....	.....	.....	See "silicon bronze"
Bronze, slide valve.....	84.50	.....	10.00	5.00	.....	P 0.5, also 88.5:9:2.5
Bronze, speculum.....	.....	.....	.....	.....	.....	See "Speculum metal"
Bronze, steam fittings.....	88.00	2.00	8.00	2.00	.....	Ni 0.71
Bronze, statutory, Augsburg.....	94.74	0.54	1.64	6.24	.....	Ni 0.48
Br., stat., Munich.....	94.12	0.30	4.77	0.67	.....	

Bronze, stat., Munich . . . . .	92.88	0 44	4 18	2 31	..	P 0 15
Br., stat., Munich . . . . .	91.55	5 50	1 77	1 30	..	
Br., stat., Col. of July . . . . .	91.40	5 60	1 60	1 40	..	
Br., stat., Potsdam (1820) . . . . .	89.78	2 35	6 16	1 33	..	Ni 0 27
Br., stat., Henri IV, Paris . . . . .	89.62	4 20	5 70	0 48	..	
Br., stat., Wittenberg . . . . .	89.55	7 45	2 99	..	..	
Br., stat., Augsburg . . . . .	89.43	..	8 17	1 05	..	P 0 34; Ni 0 19
Br., stat., Potsdam . . . . .	89.34	1 63	7 50	1 21	..	P 0 18
Br., stat., Col. Vendôme . . . . .	89.20	0 50	10 20	0 10	..	
Br., stat., Berlin . . . . .	89.09	1 64	5 82	2 62	..	P 0 13
Br., stat., Potsdam . . . . .	88.68	1 28	9 20	0 77	..	
Br., stat., Berlin . . . . .	88.30	1 40	9 50	0 70	..	
Br., stat., Munich . . . . .	77.03	0 91	19 12	2 29	..	P 0 12; Ni 0 43
Br., stat., Napoleon I . . . . .	75.00	3 00	20 00	2 00	..	
Bronze, Tobin . . . . .	59.25	40 00	0 75	..	..	
Bronze, for weights . . . . .	90.00	2 00	8 00	..	..	
Bronze, whistles . . . . .	80.00	2 00	18 00	..	..	Also 81: 2: 17
Bronze, whistles, Lafond's . . . . .	80.00	..	18 00	..	2 00	
Bronze wire . . . . .	98.75	..	1 20	..	..	P 0 05
Bushings, locomotive . . . . .	..	..	8 80	65 60	15 40	
Bushings, propeller . . . . .	5 00	69 00	19 00	..	7 00	
Bushings, Russian . . . . .	1 30	26 50	72 20	..	..	See also under "Bronze"
Bushings, turbine . . . . .	61.50	10 95	1 90	10 15	..	Ni 15.35
Button metal . . . . .	20.00	80 00	..	..	..	See also "Bronze, button"
Calido resistance wire . . . . .	..	..	..	..	..	Ni 64: Cr 8; Fe 25, Mn 3°
Calite heat-resisting . . . . .	..	..	..	..	..	Ni 35: Cr 5; Fe SO; Al 10
Calorite resistance . . . . .	..	..	..	..	..	Ni 68: Cr 12; Fe 15, Mn 8
Calorite resistance . . . . .	..	..	..	..	..	Ni 68: Cr 12; Fe 23
Camelia metal . . . . .	70.40	10 20	4 20	14 7	..	Fe 0.30
Capsule metal . . . . .	..	..	8 00	92 00	..	
Carbondale Ni silver . . . . .	66.00	16 00	..	..	..	Ni 18
Chamet bronze . . . . .	62.00	..	38 00	..	..	
Chaval Ni-silver . . . . .	58.30	25 00	..	..	..	Ni 16 70
Christofle metal . . . . .	..	..	..	..	..	Silver plated German silver

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Chromax bronze	66.70	12.10	...	...	...	Ni 15.2; Al 3; Cr 3 High tensile.
Chromel A resistance	...	...	...	...	...	Ni 80; Cr 20; "B" is 85.15
Chromel C, resistance	...	...	...	...	...	Ni 64; Cr 11; Fe 25
Chrysokalk	90.50	7.90	1.60	...	...	Also 58.7-40.2:1.1
Chrysorin	72.00	28.00	...	...	...	Also 66.67:33.33 and 63.3:36.7
Clebrum, heat resisting	...	...	...	...	...	Ni 2; Cr 13.1; Mn 0.75; Mo 3.6; Si 1.5; C 2.6; bal. Fe
Clebrum heat resist	2.00	...	...	...	...	Ni 4.6; Cr 18.5; Mn 2.8; C 2; bal Fe
Clichier's metal	...	33.00	46.00	...	...	Cd 21.0, also 50:36:14
Climax heat resisting	...	48.00	32.50	10.50	...	Bi 9.0, also Sn 80; Pb 5; Bi 15
Cobaltchrome heat resist.	...	...	...	...	...	Ni 24.4; Fe 73; Mn 2.6
Cobaltchrome non corros	...	...	...	...	...	Cr 13.6; Fe 79.5; Co 3.7; Mo 0.8; Si 0.8; C 1.5
Coin alloys	...	...	...	...	...	Cr 30-25; Co 5-10; Fe 60-70
Colorado metal	57.00	18.00	...	...	...	See "bronze coin", "gold c.", "nickel c.", "silver c."
Comet resistance	0.40	...	...	...	...	Ni 25
Condenser foil	...	...	9.25	90.00	0.75	Ni 30.4; Cr 2.2; Fe 66.9; Mn 0.8
Constantan resistance	60.00	...	...	...	...	Ni 40 also 54:46
Cook's alloy	...	31.50	...	...	68.50	Also Zn 43; Sb 57
Cooper's gold	66.60	4.15	...	...	...	Pt 29.17; also Cu 81.25; Pt 18.75
Cooper's pen metal	50.00	...	...	...	...	Ag 25; Au 25
Cooper's pen metal	12.50	...	...	...	...	Ag 37.5; Pt 50.0
Cooper's platinum sub	...	...	...	...	...	Ag 70; Pt 25; Ni 5; also Ag 70; Co 5; Pd 25
Cooper's speculum metal	57.8	3.6	27.3	...	...	As 1.2; Pt 10
Cooperite	...	...	...	...	...	Ni 80; W 14; Zr 6—cutting tools
Copel	55.00	...	...	...	...	Ni 45
Corrosion	...	...	...	...	...	About like Duriron, q.v.
Cuivre poli	70.00	30.00	...	...	...	Mn 28; Fe 2
Crokorite	70.00	...	...	...	...	Ni 22; Fe 6
Cufenium, non-corros	72.00	...	...	...	...	



Cunilloy non-corros	25.00	.....	.....	1.00	.....	Ni 65; Mn 35; parts, not per cent
Cupronickel	90.00	.....	.....	.....	.....	Mg 10; deoxidizer; sp. gr. 8.4; melts 1290°C.
Cupromanganese	90.00	.....	.....	.....	.....	Mn 10; see also manganese
Cupromanganese tubes	96.00	.....	.....	.....	.....	Mn 4
Cupronickel, coinage	75.00	.....	.....	.....	.....	A 50:50 alloy is made up for german-silver manu- facture
Cupronickel, driving bands	95.00	.....	.....	.....	.....	Turbine material (max. Fe 0.75)
Cupronickel, Imperial metal	80.00	.....	.....	.....	.....	Fe 2; Si 0.2-1.0; Mn 0.25-1.5
Cupronickel, locomotive tubes	97.00	.....	.....	.....	.....	Al 5.8
Cupronickel, monel	28.00	.....	.....	.....	.....	.....
Cupror	94.20	.....	.....	.....	.....	.....
Damar bronze	76.4	.....	.....	.....	.....	.....
D'Arceta fusible metal	67.00	.....	.....	.....	.....	.....
Davis metal (corros. resists)	80.00	.....	.....	.....	.....	.....
Delatol's metal	80.00	.....	.....	.....	.....	.....
Delhi non-corros	55.10	.....	.....	.....	.....	.....
Delta metal	55.94	.....	.....	.....	.....	.....
Delta metal, Krupp's	55.82	.....	.....	.....	.....	.....
Delta metal, Krupp's	54.22	.....	.....	.....	.....	.....
Delta metal, Krupp's	55.80	.....	.....	.....	.....	.....
Deurance metal	22.20	.....	.....	.....	.....	.....
Die casting	10.17	.....	.....	.....	.....	.....
Die casting	10.17	.....	.....	.....	.....	.....
Dilver	88.00	.....	.....	.....	.....	.....
Dirgold	1.60	.....	.....	.....	.....	.....
Doctor metal	79.60	.....	.....	.....	.....	.....
Dudley antifriction	30.00	.....	.....	.....	.....	.....
Dudley phosphor bronze	65.00	.....	.....	.....	.....	.....
Duke's non-corros	33.3	.....	.....	.....	.....	.....
Duke's non-corros	5.00	.....	.....	.....	.....	.....
Durana brass	.....	.....	.....	.....	.....	.....
Durand's cuproaluminum	.....	.....	.....	.....	.....	.....
Dunnlevic & Jones antifriction	.....	.....	.....	.....	.....	.....

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Dunnelevic & Jones antifriction.	1 60	20 00	...	60 00	20 00	Mn 0.5-0.8; Mg 0.5; bal. Al
Dunnelevic & Jones antifriction.	3 5-5 5	52 00	46 00	...	0 40	Mn 0.49; Mg 0.76; Fe 0.67; Si 0.34; bal. Al
Duralumin.	4.2	...	...	...	...	Si 14-14.5; Mn 0.25-0.35; C 0.2-0.6; P 0.16-0.2;
Duralumin.	...	...	...	...	...	S 0.005; bal Fe
Duriron.	...	...	...	...	...	Si 14-15; Mn 2-2.5; C 0.75-1.25; P 0.05-1.0;
Duriron.	...	...	...	...	...	S 0.05-0.15; bal Fe
Dutch metal	76 00	24 00	...	...	...	...
Dysoid.	62 00	10 00	10 00	18 00	...	...
Edward's Speculum.	63 30	...	32 20	...	...	As 1 6
Edward's Speculum.	69 80	2 60	25 10	...	...	As 2 4
Ehrhardt's type metal.	4 00	89 00	4 00	3 00	...	Also 3:89:6:2
Eisen-bronze	82 50	4 55	8 55	...	...	Fe 3 95
Eiseler's bronze	94 10	...	5 90	...	...	...
Electrotype metal.	...	...	3 00	93 00	4 00	...
Elkanite.	...	...	...	...	...	Like "duriron," See p. 670, also above.
Emperor brass	60 00	2 00	...	...	...	Al 20 00
Eureka resistance	...	...	...	...	...	See "manganin" and "constantan"
Excello resistance	...	...	...	...	...	Ni 85; Cr 14; Fe 0.5; Mn 0.5
Fahum brilliant metal.	...	...	...	...	...	...
Fahrig antifriction	...	...	60 00	40 00	...	...
Fahrig antifriction	10 00	...	90 00	...	...	...
Fenton's alloy.	6 00	80 00	14 00	...	14 50	Ni 18; Cr 4; Mn 2.2; W 0.5-1.0; C 0.35; Fe bal.
Fenton's alloy.	8 50	80 00	...	...	...	...
Fermet resistance.	0 30	...	...	...	...	...
Ferro-alloys see pp. 662 and 670.	...	...	...	...	...	...
Ferrozoid resistance.	...	...	...	...	...	A patented Ni-steel
Fire-armor.	...	...	...	...	...	Ni 61; Cr 18.5; bal Fe. Melts 1440°C.
"Flame-resisting"	...	...	...	...	...	Ni 9.7; Cr 14; Mn 0.77; Si 0.2; C 0.23

Fletcher's alloy	3.00	1.00	0.50	Al 95.5; Add 5PSn later as deoxidizer
Fletcher Emperor bearing	7.50	0.25	.....	Al 92.2
Foil lead (Calin)	1.00	12.50	86.50	See "Condenser foil"
Fontaine-Moreau's bronze	4.50	94.00	.....	Fe 0.50
Frary metal (bearings)	.....	.....	98.00	Ba Ca 2
French metal	.....	.....	.....	See "German silver, French"
Frick's hard Ni-silver	60.00	30.00	.....	Ni 10.00
Frick's pale yellow ductile	62.50	31.20	.....	Ni 6.30
Frick's blue yellow hard	55.50	39.00	.....	Ni 5.50
Frick's silvery	50.00	18.80	.....	Ni 31.20
Fusible metal, eutectic	Cd	15.50	32.00	Melts 96°C. See "anatomical alloy"
Fusible metal, eutectic	10.10	13.10	27.30	Melts 72°C. D'Arceet's, Guthrie's, Lipowits's,
Fusible metal, eutectic	8.10	.....	40.20	Lichtenburg's, Newton's, Union's,
Fusible metal, eutectic	20.00	26.00	.....	Melts 91.5°C.
Fusible metal, eutectic	18.00	50.00	32.00	Melts 103°C. Rose's and Wood's metals.
Fusible teaspoons	Cu	50.00	32.00	Melts 145°C.
Gedge's metal	60.00	16.50	30.00	Hg 5-10
Genger's file bronze	64.40	18.00	7.60	Fe 1.50
German silver, best	46.00	.....	.....	Also 62:10:20:8
German silver, common	55.00	.....	.....	See also "Arceet's," "Berlin," "Chaval," "Chro-
German silver, Austrian	50.00	34.00	20.00	max," "Frick's alloys," "Maillechort," "Man-
German silver, Austrian	55.60	25.00	20.00	ganneusiber," "Oreide," "Pactlong," "Rheo-
German silver, Aust. mall	60.00	22.50	22.20	tan," "Platinoid," "Silver," "Nickel silver,"
German silver, Sheffield, com	59.30	20.00	20.00	"Nickel bronze," "Tutenag," "Towcas," "Nau-
German silver, Sheffield, hard	45.70	25.90	14.80	buc," "Nickelin," "Neogin," "Sterlin," "Tur-
German silver, Sheffield, white	55.20	20.00	31.30	tuc"
German silver, electrum	45.70	.....	20.70	
German silver, electrum	51.61	.....	31.30	
German silver, bearings	50.00	25.00	25.81	
German silver, drawing	58.66	29.33	12.00	Used also for Vienna tableware
German silver, casting	55.80	23.30	13.40	
German silver, casting	69.90	4.00	3.50	Cd 4.7
		.....	19.80	

Alloys. *Continued*

	Cu	Zn	Sn	Pb	Ni	
German silver, cupping	58.00	21.50	...	0.50	20.00	
German silver, English	61.80	19.10	...	...	19.10	
German silver, flat ware	53.00	26.00	...	...	21.00	
German silver, French	58.30	25.00	...	...	16.70	Also 50:31.30:18.70 and 50.30:20
German silver, key stock	60.00	26.00	...	2.00	12.00	Also 65:22:12:1
German silver, knife bolsters	56.00	28.00	...	...	16.00	
German silver, knife bolsters	68.00	16.50	...	0.50	15.00	
German silver, milling	56.00	31.00	...	1.00	12.00	Also 56.5:28.15:0.5
German silver, milling	56.00	27.50	...	0.50	16.00	Also 54.0:27.5:0.5:18
German silver, optical wire	54.00	28.00	...	...	18.00	Also 55.27:18
German silver, resistance wire	56.50	25.50	...	...	18.00	See also under trade names
German silver, rolling	49.00	39.00	...	...	12.00	
German silver, Russian	56.20	23.36	...	...	20.40	Also 51.4.22.32.26.22
German silver, Russian	48.10	24.00	...	0.50	35.80	
German silver, show-case	58.00	24.00	...	...	18.00	Also 59.5:22.5:18
German silver, Sheffield	63.34	17.01	...	0.20	19.13	Also 54.7:37.2:17.1
German silver, Sheffield	62.63	26.65	...	...	10.85	Also 57.4:26.5:3.0:13
German silver, spoons, forks	60.00	22.00	...	...	18.00	
German silver, turbine bushing	61.50	10.95	1.90	10.15	15.35	
German silver, turning	58.50	29.00	...	0.50	12.00	Also 65:22.1:12
German silver, Wagner's	66.66	19.31	...	...	13.18	
German silver, white copper	70.00	18.00	Fe	...	12.00	
German silver, white alloy	48.00	24.4	2.4	...	22.40	Also 53.23.2.22
German silver, brazing solder	35.00	57.00	...	...	80.00	Also 45:45.10
German silver, 10 per cent	56.00	34.00	...	...	10.00	
German silver, 10 per cent	60.00	30.00	...	...	10.00	
German silver, 10 per cent	62.00	28.00	...	...	10.00	
German silver, 14 per cent	60.00	26.00	...	...	14.00	
German silver, 14 per cent	58.00	28.00	...	...	14.00	
German silver, 15 per cent	56.67	28.33	...	...	15.00	

German silver, 16 per cent	60.00	24.00	16.00		
German silver, 16 per cent	63.00	21.00	16.00		
German silver, 18 per cent	65.00	17.00	18.00		
German silver, 20 per cent	53.33	26.67	20.00		
German silver, 20 per cent	57.00	23.00	20.00		
German silver, 20 per cent	62.00	18.00	20.00		
German silver, 20 per cent	64.00	16.00	20.00		
German silver, 21 per cent	59.00	20.00	21.00		
German silver, 30 per cent	46.67	23.33	30.00		
German silver, 30 per cent	54.00	16.00	30.00		
Gilding foil	2.16	97.60	.....		Fe 0.11 See "Dutch foil"
Gluevor bearing metal	4.40	73.50	8.00 76.50	Sb	Fe 1.5
Gluevor bearing metal			6.70 5.00		Cd 1.4
Glyco . . . . .			4.50 80.50		As 0.5
Gold, Brit coin	8.33	Au			
Gold, U. S coin	10.90	91.67	Ag		
Gold, 22 carats	4.16	91.67	4.17		
Gold, 22-carat dental, dark . . .	3.44	91.57	4.99		
Gold, 22-carat dental, light . . .	.....	91.57	8.43		
Gold, 20 carats	8.33	83.33	8.33		Also 5.99:83.20:10.81
Gold, 18 carats	14.60	75.00	10.40		Also 13:75:12 and 10.4:75:14.6
Gold, 18-carat dental	5.00	75.00	20.00		Also 5.99:74.88:19.13
Gold, 16-carats	26.67	66.67	6.66		Also 22.22:66.66:11.12
Gold, 16 carats	7.98	66.45	25.57		Also 13.90:66.67:19.43
Gold, 14 carats	28.34	58.33	13.33		Also 37.50:58.33:4.17
Gold, 14-carat spring	25.67	58.33	16.00		
Gold, 14-carat dental	11.94	58.03	30.03		Special is 13.9:58.33:27.77
Gold, 12 carats	35.42	50.00	14.58		
Gold, 10 carats	46.00	41.66	12.34		Also 41.67: 41.67: 16.66
Gold, 10-carat spring	38.34	41.66	20.00		
Gold, 8 carat	46.67	33.33	20.00		Fe 25.0
Gold, blue.		75.00			Fe 5.7; also Au 83.33; Fe 16.67
Gold, gray		85.70	8.60		

ALLOYS. *Continued*

	Cu	Au	Ag	Pb	Sb	
Gold, green . . . . .	75 00	25 00				Also Au 74.6; Ag 11.4; Cd 4.3; Cu 9.7
Gold, green . . . . .	75 00	12 50				Cd 12.50 Also 75; 16.67; 8.33
Gold, palladium . . . . .	90 00					Pd 10; "white gold"
Gold, red . . . . .	25 00					Dark red is 50-50
Gold, white . . . . .	90 00					Pd 10; also Au 75-85; Ni 10-18; Zn 2-9
Gold, yellow . . . . .	22 00	53 00	25 00			
Gold, yellow, pale . . . . .		91 67	8 33			Also Au 91 67; Fe 8 33
Gold solder, 18 k . . . . .	12 00	75 00	13 00			Also 8.33; 75.00; 16.67
Gold solder, 16 k . . . . .	6 25	62 50	31 25			14 k. solder is 16.67; 50 0; 33 33
Gold solder, 12 k . . . . .	17 10	47 80	29 00			Brass 6.1
Gold solder, 10 k . . . . .	21 20	41 20	37 00			Brass 0.6
Gold solder, 8 k . . . . .	23 40	40 00	36 60			
Gold solder, best . . . . .	15 00	62 50	22 50			
Gold solder, easy melt . . . . .	13 75	54 50	31 75			

	Cu	Zn	Sn	Pb	Sb	
Gold leaf, imitation . . . . .	66-84	34-10				
Gold leaf, Aix . . . . .	64 80	32 80	2 00	0 40		
Gold leaf, Jamappes . . . . .	64 60	33 70	1 40	0 20		
Guettier's button metal . . . . .	56 00	44 00				
Guettier's button metal . . . . .	61 50	32 00	6 50			Also 61.4; 28.9; 9 7
Gun metal, Turkish, 1464 . . . . .	95 20		4 71			
Gun metal, Chinese, 1901 . . . . .	93 20		5 05			Fe 1 72
Gun metal, Cochín China . . . . .	93 19		5 43			Fe 1 38
Gun metal, U. S. A. . . . .	92 50	2 50	5 00			Also 91.2; 7
Gun metal, Brit. mod . . . . .	91 74		8 26			Also 89.3; 10 7
Gun metal, Prussian, mod . . . . .	90 90		9 10			Modern Russian 90.8; 9.2

Gun metal, Turkish, 1907	90 90	8 80	Fe 0.20	
Gun metal, French, modern.	90 10	9 90		
Gun metal, U. S. A.	90 00	10 00		
Gun metal, old French.	89 44	8 91	0.16	
Gun metal, Swiss	88 93	10 37	Fe 0.69	
Gun metal, Russian, 1813	88 61	10 70		
Gun metal, U. S. A.	87 75	9 75	Melts 1825°F.	
Gun metal, U. S. A.	83 00	5 00	With 3 per cent. Pb, melts at 1795°F.	
Gun metal, U. S. A.	83 00	2 00		
Gun metal, Cochiti China	77 18	3 42	Fe 1.16	
Gun metal, old Chinese	71 16	27 36	Fe 1.40	
Graney bronze.	75 80	15 00	Also known as Gurney's bronze	
Gurley's metal	86 50	5 40	Used for transit frames	
Guthrie's metal.		19 97	Bi 47.38; Cd 13.29, melts 71.1°C.	
Guthrie's metal.		19 97	Bi 47.38; Cd 13.29, melts 160°F.	
Halberland alloy	87 00	13 00	PSn 5; for bearings	
Hamilton metal	3 50	93 40		
Hamilton metal	66 67	33 33		
Hard head.	2 00	90 00	Term applied to all Sb-Pb alloys	
Hard lead.	0 50	7 50	Ni 15 0; Harness trim. Casts well; doesn't roll	
Hardware metal	50 00	80 00		
Harlington bronze.	55 70	34 90		
Harmonia bronze	55 70	42 70		
Harmonia bronze	57 00	41 20	Al 0.86	
Harmonia metal.	3 25	40 00	Fe 1.8	
Hartzink	0 13	32 25		
Haynes' metal		91 90	Fe 5 3	
Haynes' metal, hard			Cr 20-30; Co 5-25; Fe 75-10	
Herbolin bronze.	71 43	2 70	Cr 15; Co 45; W 40; soft, Cr 10; Co 62; W 28	
Hercules bronze.	85 50	2 00	Also 60; 5; 35	
Hercules brass.	54 00	36 00	Al 2.5; Fe 7.5	
Heusler's alloy	66 50		Al 11 1; Mn 22 4; see p. 664	
Heusler's alloy	68 00	4 00	Al 10 0; Mn 18 0	
Heusler's alloy (max.)	61 00		Al 13 0; Mn 26 0	

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Hooker brass	61 00	37 00		2 00		Fe 0.22
Hoyle's metal			46 00	42 00	12 00	Mg 0.5; Ni 1.25; Co 0.25, (MnSnCd 0.5); bal. Al
Husman metal	4 00	0.18	73.60	10.60	11 00	Mn 0.6; Mg 0.5; Cr 0.1 bal Al
Huron A-5 castings alloy	6 6					Mn 0.6; Mg 0.5; Cr 0.1; bal Al
Huron A-rolled	3 5					
Huron B-rolled	4 0					
Huron D-rolled	4 0					Mg 0.5, Cr 0.6; bal Al
Huron Al-ingot, 11	6 60	2 30				A. 88.85; Mn 1; Ni 1.25
Huron casting, 12	8 00					Al 92, #21 is Al 90; Cu 10
Huron casting, 22	6 30	5 00	5 00			Al 83.7
Huron casting, 31	3 0	16 00				Al 80.5; Mn 5
Huron casting, 32		36 00				Al 64; #33 Al 81, #34 Al 78, bal Zn
Huron rolling, 3.5						
Huron rolling, 5.5	2.00	2 00				Al 98.5; Mn 1.5
Huron rolling, 8.5		33 33				Al 94.5; Mn 1.5
Hydraulic bronze	75.00	14 00	11 00		Ni	Al 66.67
	83.00	5.00	5 00	5 00	2.00	For pressures up to 3,000 lb. per sq in.
Ia-la resistance	60.00			40.00		
Ideal resistance	53 40			45 00		Fe 0.66; Mn 0.45; Al 0.66
Ideal resistance	58.00			40 00		Fe 1.0; Mn 1.0
Illum Pt-substitute	6.50			62 50		Cr 21; Fe 1; Mo 5, W 2; Mn 1; Al 1
Imperial cupronickel	80.00			20.00		Mn-bronze with aluminum
Immadum bronze						
Invar				36 00		Fe 64.00. See p. 666
Iridium substitute	1.12	77 25	21 63		tr	
Iridium substitute	1.25	83 00	15 75		tr	
Ironac				Pb		Similar to "Duriron," q v
Iserlohn brass	63 70	33.50	2.50	0 3		



Jacana metal	5 00	10 00	70 00	20 00	Classical references
Jacoby metal	87 50	7 85	5 07	10 00	As given by Wm Campbell
Johnson loco. bearing.	3 60	1 40	85 00	5 00	Bi 1 6
Kamarsch bearing	9 50		70 70	3 40	80 Ni, 20 Cr; melts 1415°C.
Kamarsch bearing					See "Bronze, Karakane"
Karma					Al 15.0
Karakane	9 00	76 00			
Kernier	78 00	10 00	12 00		
Kern's hydraulic bronze					
Kneiss bearing metal		50 00	25 00	25 00	Ni 80; Cr 20
Kneiss bearing metal	3 00	40 00	15 00	42 00	Ni 85, Cr 15. See p. 666.
Kochlin's bearing	90 00		10 00		28 per cent nickel steel
Kromax resistance					
Kromore resistance					
Kruppin resistance					
Krupp's V 1 M non-corros					
Krupp's V 2a non-corros	78 00	10 60		10 45	Cr 14 25; Ni 2 25 C 0 1; bal Fe
Kuhne's phosphor bronze					Cr 23 00; Ni 9 5, C 0 4; bal Fe
					Ni 0 26; P 0 57
L-5 aluminum	2 5-3 0	12 5-14 5			Bal Al
Ladberg's speculum	69 00		28 70		
Ladberg's speculum metal	80 00	2 00	18 00		
Lafond's axle bearing	83 00	1 50	15 00	0 50	
Lafond's bronze (heavy bearing)	83 04		1 96		
Lafond's malleable bronze	88 00	2 00	10 00		
Lafond's pump bronze					
Lafond's strap bronze	84 00	2 00	14 00		
Lancashire brass	73 00	25 00		2 00	
Lead bronze	88 50	10 00		1 50	
Leddel alloy	5 00	5 00			Al 5
Leddel bearing	6 25	87 50			Al 6 25
Ledebur's bearing	5 00	85 00		10 00	
Ledebur's bearing	5 50	77 00	17 50		
Lemaquand's non-oxidizable	39 00	37 00	9 00		Co 8 0; Ni 7 0

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Liberty piston	1.06	21.30	0.12	0.33	.....	Fe 0.47; Al 76.6
Lichtenberg's alloy	.....	.....	20.00	30.00	.....	Bi 50; melts 94.5°C.
Linotype, English	.....	.....	5.00	83.00	12.00	.....
Linotype, American	.....	.....	3.00	85.00	12.00	.....
Lipowitz's alloy	.....	.....	13.30	26.70	.....	Bi 50; Cd 10; melts 70°C.
Lowruff's phosphor bronze	70.00	.....	13.00	16.00	.....	P 1; also 90:4:5:5:0.5
Lucero resistance	27.50	.....	.....	.....	.....	Ni 67.9; Fe 2.4; Mn 2.2
Ludenscheidt brass	82.30	17.50	.....	.....	.....	For buttons, 20 Cu:80 Zn
Ludlum heat resisting	.....	.....	.....	.....	.....	Cr 13-17; Si 1, C 0.4; Mo 1; bal Fe
Lumen bearing	10.00	86.00	.....	.....	.....	Al 4; also 85:10:5
Lunge's resistance alloy	86.50	.....	.....	.....	.....	Mn 11.7, Fe 1.8; also 84.32:13.45:1.9
Lynite, #109	7-8.5	.....	.....	.....	.....	Bal. Al; #122, Cu 9½-103%; #146, Cu 7-8½
Lynite body alloy	5.00	.....	.....	.....	.....	Bal. Al
Lynite crankcase	7.83	1.50	.....	.....	.....	Fe 1.25; bal. Al
Lynite piston	11.03	.....	.....	.....	.....	Mg 0.25; bal. Al
Lynite piston	2.14	.....	.....	.....	.....	Mn 0.07; Mg 1.5; Fe 0.76; Si 0.23; bal. Al
Mach's alloys	.....	.....	.....	.....	.....	Mg 2-10; bal. Al
Mackenzie's alloy	.....	.....	.....	68.00	16.00	Bi 16.00; stereotype metal
Mackenzie's alloy	.....	.....	13.00	70.00	17.00	Stereotype metal
Magnalium x	1.76	.....	.....	.....	.....	Mg 1.6; Ni 1.16; bal. Al
Magnalium z	0.21	.....	3.15	0.07	.....	Mg 1.56; bal. Al
Magnalium cast	.....	.....	.....	.....	.....	Mg 15.00; Al 85.00
Magnalium sheet	.....	.....	.....	.....	.....	Mg 5.00; Al 95.00
Magnalium sheet	.....	1-20	.....	.....	.....	Mg 1-10; bal. Al
Magnalite	2.00	.....	.....	.....	.....	Mg 2.0; Ni 2.0; bal. Al
Magnalite	2.50	0.5	.....	.....	.....	Mg 1.3; Ni 1.5; bal. Al
Magnalite	2.40	.....	.....	.....	.....	Mg 1.56; Ni 1.19; Fe 0.47; Al 93.9
Magnalite	2.32	.....	.....	.....	.....	Mg 1.46; Ni 1.35; Fe 1.22; Si 0.49; Al 93.15
Magnalite	2.47	0.13	.....	.....	.....	Mg 1.17; Ni 0.65; Fe 0.69; Si 0.59; Al 94.27
Magnalite	2.61	.....	0.17	.....	.....	Mg 1.37; Ni 1.72; Fe 0.8 Si 0.37; Al 93.50

Magnesium resistance	...	...	6.00	78.00	16.00	Ni 95.0; Mn 5.0
Magnolia metal	...	...	5.00	79.75	15.00	Bi 0.25
Magnolia metal	...	...	...	...	...	Ni 16.8; Fe 3.4
Maillechort	...	65.40	...	0.22	0.15	Ni 13.32; Fe 3.21
Maillechort, Paris	...	66.24	...	...	...	Ni 19.3; Fe 0.48
Maillechort, Vienna	...	66.60	...	...	...	
Mallet alloy	...	25.40	...	...	...	Mn 0.1; Fe 1.4; Si 0.2
Maluminium	...	6.40	...	0.15	...	Fe 16.0
Manganese brass, Ponsard's	...	60.00	...	...	...	Al 1; Si 0.5
Manganese brass, Ponsard's	...	50.00	...	...	...	Fe 2.4; Ni 0.5
Manganese brass, Ponsard's	...	75.00	...	...	...	Fe 0.7; Al 0.5
Manganese brass, Cowles'	...	67.50	...	...	...	Fe 2.25; Ni 2.2; Al 0.25
Manganese brass, Cowles'	...	75.50	...	...	...	Fe 1.44; Ni 2.14
Manganese brass, Cowles'	...	80.00	...	...	...	Fe 1.06; Al 0.2
Manganese brass, Rheotan	...	84.00	...	...	...	Fe 1.9; Al 0.23
Manganese brass	...	54.20	...	...	...	Ni 2.50; Al 0.2
Manganese brass	...	55.00	...	...	...	Fe 2.78; Ni 2.53;
Manganese brass	...	51.15	...	...	...	
Manganese brass	...	53.51	...	1.22	...	
Manganese brass	...	55.40	...	...	...	
Manganese brass	...	60.15	...	0.94	0.39	
Manganese brass	...	53.40	...	2.66	...	
Manganese brass	...	53.50	...	...	...	
Manganese brass	...	69.50	...	...	...	
Manganese brass	...	59.00	...	1.00	...	
Manganese brass	...	58.00	...	...	...	
Manganese bronze	...	85.75	...	14.00	...	
Manganese bronze	...	86.30	...	6.00	...	
Manganese bronze	...	83.50	...	8.00	3.00	
Manganese bronze, Parsons	...	60.15	...	0.94	0.39	
Manganese copper	...	89.70	...	...	...	
Manganese copper	...	85.55	...	0.39	0.45	
Manganese copper	...	85.00	...	...	...	
Manganese copper	...	85.00	...	...	...	

## Alloys. Continued

	Cu	Zn	Sn	Pb	Mn	
Manganese copper	84.33	2 10	0.4	....	10.61	Fe 2.31
Manganese copper	75.30				22.40	Fe 2.15
Manganese copper	75.00				25.00	
Manganese copper	56.30				40.90	Fe 1.5, Si 1.1
Manganese copper	29.20				51.65	Fe 9.68; Al 6.25; C 3.23
Manganese cupro nickel	83.12				15.02	Fe 0.6; Ni 2.3
Manganese cupro nickel	78.30				14.10	Ni 7.6
Manganese cupro nickel	73.00				24.00	Ni 3.0, also 70:25.5
Manganese cupro nickel	65.00				30.00	Ni 5.0, also 51.5:31.3:16.2
Manganese nickel	72.25	8.75			5.00	Ni 95 Melts 1420°C
Manganese nickel silver	63.50	28.28	1.22	0.17	2.43	Ni 16.57; Also 65.5:20:10
Manganese silver					3.24	Ni 2.14; Fe 1.44
Manganese silver	60.00		10.00		20.00	Ni 10.0
Manganese silver	59.00	20.00			3.00	Ni 18.0; Also 65.5:10:20
Manganese silver	53.50	39.00	0.07		1.52	Ni 2.35; Fe 2.78
Manganese silver	51.15	40.00			4.15	Ni 2.2; Fe 2.25, Al 0.25
Manganese steel					12.00	C 1.2; bal Fe; resistance alloy.
Manganin	84-86				12.00	Ni 2-4 } has negative coefficient of resistance
Manganin	84.00				4.00	Ni 12.0 }
Manganin					1.70	Ni 2.5; Al 0.2
Manganin	53.40	39.00	2.66		15.00	Ni 2.3; Fe 0.6 } See pp. 198 and 667
Manganin	82.10				25.00	Ni 5.0
Manganin	70.00					See "Manganese nickel-silver"
Manganin-silver						Mg 0.05, P 0.07; Al 83.33
Mango, Manhardt's alloy	6.24		10.00			
Mannheim gold	89.20	9.92	0.62			PSn 5.0
Mannheim gold	83.70	9.30	7.00			Also 80:20 (Prince's metal)
Mannheim gold	88.00	12.00				Cr 25, Ni 75; resistance
Marsh's Patent alloy						Fe 10, Ni 35
Marties' non-oxidizable	17.00	18.00	10.00			

McAdams, W. A.: Imitation silver Imitation silver Imitation silver Imitation silver	7 70 5 00 12 00 3 00	23 10 20 00 22 00	80 00	Ni 0.63; Al 68 5 Ag 16.5; Al 60; Also 5:26:1.70 Ag 1; Cd 5; Al 82 Sb 5; Al 70 Cd 8; Ag 4; Al 80
McAdamite McFarland & Harder McFarland & Harder McKee's bronze McKinney's casting Al McKinney's forging Al	3 10 11 00 43 00 50 50 2 00 2 00	12-18 ..... ..... 1.00 .....	41.00 0 50 ..... .....	Mg 0.2; bal Al Ni 46; Cr 43; Also 11:59:30 Ni 48; Cr 9; Also 55:29:16 Fe 1.00 Al 96 00 Al 96 5; Also 3:2:94.5
McLure's Aluminum Metaline Metallic packing, French Meteorite Minargent Minofor (Britannia)	8 20 30 00 ..... 46 00 3 30	..... ..... 1-2 10.00	5-6 14.00 76 00 ..... 22 00 68.50	Fe 0.9; Si 0.3; bal Al Al 25; Fe 10; Co 35 Sb 10.0 P 1-4; bal Al Ni 32 00; Also made with W 2 8 Sb 18 2; Also 4:9:66:20 with FeO 1.0
Misco Mira Monel metal, forged Monel metal, cast Morin's Chinese bronze Mosac gold	74 70 28.40 28 00 83 00 65.00	..... 0.62 ..... 2 00 35 30	..... 16 30 ..... 5.00 10.00	Fe 57.5; Cr 15; Ni 25; Si 1.50, C 0.5 Fe 0.43; Ni 0.24; Anti-acid Ni 67 1; Fe 2.1; Si 0.20 } melts Ni 68.0; Fe 2.1; Si 1.00 } 2400°C.
Mudge's speculum Muntz metal Murman's aluminum Mystic metal	68 82 60 00 ..... .....	31.18 40 00 4.40	..... ..... 88.70	Also 62:38 Al 92; Mg 3.6; Also 72:14 5:13.5 Sb 10 80; Bi 0.1; Fe 0.4
Naubac knife stock Navy aluminum Navy al-bronze Navy bearings	58 00 1 50 85 87 3 70	16 25 ..... ..... .....	..... ..... 89.00	Ni 25; Fe 0.75 Fe 0.40; Si 0.30; bal Al Fe 2.5-4.5, Al 7-9 Sb 7.3

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Ni	
Navy bearings, hard	5.00	2.00	80.00			Sb 15.0
Navy gun metal, G	88.00	10.00				
Navy journal, H	83.00	3.50	13.50	3.50		
Navy journal, Hx	83.00		8.00			P 0.5
Navy phosphor, cast	88.00	2.50	4.50			P 0.5
Navy phosphor, rolled	95.00					
Navy valve bronze	87.00	6.00	7.00			Extremely fluid
Needle metal	84.96	5.31	7.96	1.77		Bi 0.5; Al 0.5
Neogen nickel silver	58.00	27.00	2.00		12.00	See "German silver" and Ni-neusilber
Neusilber						Cr 9.5; Si 3.8; CO 43, bal. Fe
Neustadt brass	71.5	28.50				For spoons and forks.
Neustadt non corros						Bi 50.0; melts 94.5°C.
Newloy	64.03		1.00		35.0	Cr 16; Fe 8; Mn 3; Also 40:7:50:3
Newton's metal			18.75	31.25		Cr 20; Fe 50; Mn 1 with some Al; Si, C and V
Nichroloy resistance					75.00	Cr 11; Fe 25; Mn 4. See pp. 197, 198 and 667.
Nichroloy resistance					23.00	Cr 11; Fe 12; Mn 2
Nichrome I resistance					60.00	Cr 22; Fe 10; Mn 2
Nichrome II resistance					75.00	Cr 13.55; Fe 4.8; Si 1.3
Nichrome resistance					66.00	Cr 20.0; Fe 6.9; Mn 1.9; Si 0.5
Nichrome heat resisting					80.00	Cr 13.2; Fe 7.25; Mo 1.33; Si 3.7
Nichrome heat resisting	3.25			Mn	70.30	Cr 11.3; Fe 6.95; Si 4.65; Ti 0.25
Nichrome heat resisting	7.10			0.20	67.80	Cr 13.3; Fe 6.40; Si 3.36; C 0.35
Nichrome heat resisting	11.00			0.63	64.70	Cr 13; Fe 20
Nichrome heat resisting					62.00	Cr 9.9; Fe 26.9; Si 0.3
Nichrome heat resisting				5.00	61.20	Cr 11.1; Fe 27.2; C 0.3
Nichrome heat resisting				1.20	60.20	Cr 16.7; Fe 22.4; Si 1.0
Nichrome heat resisting				1.40	53.70	Fe 0.5; see also "German silver"
Nickel brass	54.10	43.66			1.50	Al 0.1
Nickel brass	50.00	34.90			15.00	

Nickel bronze .....	61 50	10 95	1 88	10 15	15 35	
Nickel bronze .....	60 00	12 00	8 00	20 00	20 00	
Nickel bronze .....	58 00	18 00	2 00	18 00	12 00	
Nickel bronze .....	47 00	21 00	1 00	30 90	30 90	Bi 0.1
Nickel coin, U. S. ....	75 00			25 00	25 00	
Nickelin resistance .....	55 30	13 10		0 18	31 07	Fe 0.43
Nickelin resistance .....	62 00	20 00			18 00	
Nickelin resistance .....	68 00				32 00	
Nickel oreide .....	86 66	6 66			6 66	
Nickel oreide .....	65 50	32 66			2 00	Also 64:32:4
Nickel oreide .....	63 33	31 66			5 00	Also 63.33:30.66:6
Nickeloy .....	4 15				1.41	Al 93.8
Nickel silver .....						See German silver, also Argentan, maillechort, packfong, sterlin, tutenag, white copper, etc.
Nickel steel .....					30 00	Mn 1.0; Cr 1.0; bal. Fe
Nickel-zirconium .....					86 40	Si 6; Zr 1.5; C 0.1; Al 6 cutting tools
Non-magnetic high-resistance .....	39 00	37 00	9 00		30 00	Cr 70.0
Non-oxidizable, Lemarquand's .....					7 00	Co 8.0
Non-oxidizable, Marties' .....	17 00	18 00	10 00	Pb	35 00	
Noheet bearing .....			0 08	98 41	0 11	Na 1.4
Nongran .....	87 00	2 00	11 00	Pb		
Nonpareil bearing .....			4.95	78 35	16 7	
Oker brass (Harz) .....	64 24	37 27	0 59	0 12		Fe 2.32
Oker brass (cast) .....	71 90	24 40		1 10		Bi 50.00; Melts at 917°C.
Orion's alloy .....			20 00	30 00		Al 3; "M" is 95.5
Oranium bronze S .....	97 00					Al 8.5; "H" is 90:10
Oranium bronze MH .....	91 50					Al 11; "HH" is 88.5:11.5
Oranium bronze HX .....	89 00					Also 85 5:14 5
Oreide .....	90 00	10 00				
Oreide .....	87 25	11 50	1 25			
Oreide .....	80 50	14 50	4 85	0 10		See also "Nickel oreide"
Oreide, Brunswick .....	68 21	31 52	0 48			
Ormolu .....	58 00	23 30	16 70			
Ormolu, large .....	90 50	3 00	6 50			

Alloys. *Continued*

	Cu	Zn	Sn	Pb	Misc.	
Ormolu, small Ounce metal	94 12 85 00	5 00 5 00	5 88 5 00	5 00		
Packfong					Ni	
Packing, Russian	43 80 40 40	15 60 25 40	..	..	40 60 31 60	Also 26 3:36 8:36 8 Fe 2 6 Fe 0 16
Packing, Russian	1 30	98 50	0 98	0 32	..	
Palau (Pt substitute)	..	26 50	72 20	..	..	
Palau (Pt substitute)	..	..	..	..	..	Au 80, Pd 20 Pt 20, Pd 10; V 10
Palladium gold	39 65	..	..	..	60 00	
Parr's noncorrosive	5 00	..	..	..	..	Pd 10 35; Au 31 0, Ag 19 0 Cr 15 00
Parr's noncorrosive	8 50	..	..	..	80 00	Cr 18 00; W 3 3; Al 2; Mn 1; Ti 0 2; B 0 2
Parsons' white brass	5 00	35 00	60 00	..	66 60	Also 5 30:65
Parsons' white brass	4 50	..	81 00	3 50	11 00	Also 5 76:13:6 W 0 8; bal. Al
Partinium	0 64	..	0 16	..	2 40	
Partinium	7 40	1 70	..	..	..	Fe 1 3; Si 1 1; Al 88 5
Perking brass	80 00	0 14	19 82	..	..	Also Cu 76 2; Zn 23 8
Periscope alloy	53 00	34 00	..	..	..	Ni 9; Al 0 35; Mn 1 5; Fe 15
Pewter	3 54	0 88	88 42	20 00	7 16	
Pewter	1 80	..	89 30	1 80	7 60	Also 1 6:81 2:11 5:5 7
Pewter	6 80	..	84 70	..	1 70	Bi 6; Also 1 8:89 3 7 6:18
Pewter	1 00	..	73 50	20 00	5 50	According to Thurston
Pewter, Berthiers	71 90	24 90	1 20	2 00	..	Also 61 6:35 3 0 6:2 5
Pewter, cast	64 20	34 60	0 20	2 00	..	Also 64 5:32 4 0 2:2 9
Pewter, cast gilt	63 70	33 50	2 50	0 30	..	Also 60 06:31 46:1 43:0 88
Pewter, for clock work	60 66	36 88	1 35	0 74	..	
Pierrot metal, Beugnot	8 30	83 30	7 60	3 00	3 50	Ni 25; Fe 75
Phenix resistance	98 75	..	1 20	..	P	
Phos bronze, wire	..	..	..	..	0 05	



Phos. bronze, rolling	95.60				0.10	
Phos. bronze, sheet	95.00	4.50			0.10	Also 94.5:5.45:0.05
Phos. bronze, Russian	93.70	5.80	0.34		0.17	
Phos. bronze, hard	92.80	7.00			0.20	Very hard 80:9:1
Phos. bronze, Law's	88.70	9.50			0.70	Also 87.6:10.8:1.0
Phos. bronze, Charpy's	85.70	12.20			0.40	Also 84.8:13.4:0.46
Phos. bronze, gears	88.00	10.00		2.00	0.10	Also 78.12.7.5:0.1
Phos. bronze, gears	85.00	13.00	2.00		0.10	P.0.1
Phos. bronze, gears	79.90	12.00		7.50		Also 76.8:8:15:0.2 and 79.7:10:9.5:0.8
Phos. bronze, Penna R R "B"	80.00	9.80		10.00	0.20	
Phos. bronze, Penna. R R.	85.55	9.85	3.77	0.62	0.05	Also 85:15.1
Phos. bronze, bridge	80.00	20.00			0.1-0.2	
Phos. bronze, bearings	83.00	14.00	2.00	1.00	1.00	An English alloy
Phos. bronze, bushings	79.20	19.60		10.20	0.97	Also 90:10
Phosphor tin		95.00			5.00	Also 83.33:16.67 and 93.6:6.4
Pinchbeck (brass)	88.20		11.20			
Piston packing, Cie. du Nord		12.00		73.00	Sb	
Piston rings, Stephenson's	84.00	2.90	8.30	4.30	15.00	
Placet (resistance)						Fe 0.4
Plastic bronze	65.00	5.00		30.00		Ni 60, Fe 20, Cr 15, Mn 5
Plastic metal	9.50	80.50			8.60	Fe 1.4
Platine	43.00		57.00			Pt 17-35; Ag 83-65
Platine-au-titre						Ni 46-42; Fe 54-58
Platinite (resistance)						Ni 24.77; Fe 0.47; Mn 0.15
Platinoid (resistance)	54.00		20.40			Ni 14; W 1-2; Sp. gr. 13.6; Coeff. exp. 0.0000036
Platinoid (resistance)	60.00		24.00			Pt 40; Au 60; almost white 30:70
Platinum-gold (white)						Pt 58.3; Au 16.6; Ag 25
Platinum-gold (almost white)						Pt 33.3; Ag 66.6
Platinum (resistance)						Pt 27.0; Ag 73.0
Platinum solder						Pt 90; Ir 10; also Pt 90:Rh 10
Platinum thermocouples						Al 23.6; Ni 0.72; Bi 3.7; Au 0.7
Platinum substitute						Pt 5; Ag 25; Au 70; also 7.5:25:67.5
Pt sub. (electrical)						

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Pt sub. (electrical)						Au 70; Ag 25; Ni 8 (see also "Palau")
Platnam	32.55			12.72		Ni 58.8; Fe 0.48; Al 0.32 valve seats
Poterie d'étain	1.00		90.00		9.00	
Potiniabne	71.90	24.90	1.20	2.00		
Prince's metal			84.75		15.25	
Prince's metal	83.00	17.00				Also 75:25; and 60.8:39.2
Propeller bushings						
Proplatinum	5.00	69.00	19.00		7.00	
Pump cocks	7.00	72.00	21.00			Au 0.75; Ag 23.5; Ni 72; Bi 3.75
Queen's metal	3.50	0.90	88.50		7.10	Also 3.5:1.0:87.0:8.5
Queen's metal	3.50		88.50		7.00	Bi 1.00
Queen's metal		8.88	73.36	8.88	8.88	Also 16.5:50.5:16.5:16.5
Rakel's metal	87.50	1.00				Al 10.5; Mn 1.00
Rayo (resistance)						Ni 85; Cr 15
Red metal	70.00	20.00	4.00	6.00		
Reich's bronze	85.15					Al 0.6; Fe 7.5; Mn 0.5
Resistol (heat resisting)						Ni 16.56; Cr 15.14; Si 4.66; C 0.3; bal. Fe
Resistal (resistance)	86.50					Mn 11.7; Fe 1.8; also 85:12:3
Rheotan (nickel-silver)	52.00	18.00				Ni 25; Fe 5
Rheotan (resistance)	84.00	4.00				Fe 10; Mn 2; also Cu 84:Zn 4: Mn 12
Rheotan II (resistance)	52.00	18.00				Ni 25; Fe 5
Richardson's speculum	65.30	0.70	30.00			As 2; Si 2
Roberts-Austen's purple gold						Au 78.5:Al 21.5
Roman bronze	90.00		9.00			
Romanium	0.25		0.15		0.25	W 0.17; Ni 1.75; bal. Al
Rosein			20.00			Ni 40; Ag 10; Al 30. Cheap jewelry
Rose's metal (fusible)			22.00	28.00		Bi 50; melts at 93.75°C.
Rose's metal (fusible)			30.00	35.00		Bi 35

Ross' alloy	68.20	31.80	.....	.....	Al 72
Rozenhain & Archutt forging aluminum	3.00	25.00	.....	.....	5 per cent of Al-Fe-Mn-Ni alloy
Rubel metal I	55.00	40.00	.....	.....	5 per cent of Al-Fe-Mn-Ni and 4 per cent. ferro-Mn
Rubel metal II	51.00	40.00	.....	.....	
Salge metal	4.00	85.50	9.90	1.1	Ni 4.10
Salit's speculum	64.10	31.30	.....	.....	
Schmidt loco. bearing	86.00	14.00	.....	.....	Fe 0.15
Schomberg bearing	0.38	59.40	39.80	0.21	Cr 1.2; Ni 24; Mn 0.6; Si 0.35; C 0.5; Fe bal
Seawater, non-corrosive	.....	.....	.....	.....	Ni 16.7; Mn 5; Si 0.3; C 0.7; Fe bal.
Seawater, non-corrosive	.....	.....	.....	.....	
Seawater, bronze	45.00	5.50	16.00	.....	Ni 32.5; Bi 1.0
Secretan	91-95	.....	.....	.....	Mg 1.5; P 0.5; Al 9-5
Serasing bearing	86.00	.....	14.00	.....	
Serasing piston rings	89.00	9.00	2.00	.....	Ni 24; see also "German silver"
Sheffield German silver	57.00	19.00	50.00	33.00	17.00
Ship's nail alloy	.....	.....	.....	.....	
Shot lead	.....	.....	.....	99.8	As 0.2
Sibley alloy	.....	33.00	.....	.....	Al 67.00
Sideraphite non-corros	5.00	.....	.....	.....	Ni 23.00; Fe 63.00; W 4; Al 5
Siemens & Halske	.....	48.00	.....	5.00	Cd 47; also 47.5:5:47.5
Silchrome (heat resist)	.....	.....	.....	.....	Cr. 9.5; Si 4; C 0.5; bal. Fe
Silchrome wire	.....	.....	.....	.....	Cr 18.0; Si 3; C 0.3; W 3.0; bal. Fe
Silicon bronze	97.12	1.12	1.14	.....	A little Si. Very high tensile
Silicon bronze	98.52	.....	1.43	.....	Si 0.05; Also 90.97:8.98:0.5
Silver	73.3	12.10	.....	0.51	Mn 12; Fe 1.8; Al 0.25
Silver	67.93	15.84	.....	0.48	Mn 6.8; Fe 2.22; Ni 6.5; Al 0.13
Silver bronze	67.50	13.00	.....	.....	Mn 18; Al 1.25; Si 0.25
Silver foil	.....	10.00	90.00	.....	Also Sn 97.5; Cu 2.5
Silver foil	.....	8.25	91.00	0.35	Ag
Silver "metal"	.....	66.5	.....	33.50	
Silver, U. S. coin	10.00	.....	.....	90.00	
Silver, rupee coin	8.30	.....	.....	91.60	
Silver, sterling	7.50	.....	.....	92.50	
Silver solder, Bur. Standards	14.00	6.00	40.00	40.00	Melts 1640°F. Poured around 2100°F.

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Ag	
Silver solder, chain	20 90	16 60	.....	.....	63 50	Also 31.2:6.2:62.5
Silver solder, common	30 00	7 50	.....	.....	62 50	
Silver solder, enamel	33 30	.....	.....	.....	66 70	
Silver solder, French	23 30	10 00	.....	.....	66 00	
Silver solder, hard	13 20	6 80	.....	.....	80 00	Also 13:7:80
Silver solder, medium	20 00	5 00	.....	.....	75 00	
Silver solder, pure silver	28 00	.....	.....	.....	72 00	
Silver solder, plate	22 50	13 00	.....	.....	64 50	
Silver solder, quick	20 90	10 40	6 20	.....	62 50	Also 27.7:11.5:3 8:50 9
Silver solder, sterling	2 50	17 50	.....	.....	80 00	
Similar	89 40	9 93	0 60	.....	.....	Also 83 7:93:7.0 and Cu 80:Zn 20
Smutter-Lemian Ni-Ag	72 00	9 75	2 25	.....	.....	Ni 12.75; Fe 2; Bi 1
Solder, for aluminum	.....	.....	39 00	60 00	Sb	See "Aluminum solder"
Solder, antimonial	.....	.....	.....	.....	1 00	
Solder, brass, hard	57 00	43 00	.....	.....	.....	See also "Brass solder"
Solder, for brazing	35 00	57 00	.....	.....	.....	Ni 8, also 45:45:10
Solder, for German silver	45 00	45 00	.....	.....	.....	Ni 10; melts easily, flows well
Solder, for gold	.....	.....	.....	.....	.....	See "Gold solder"
Solder, for lead pipe etc	.....	.....	50 00	50 00	.....	Also 40:60 and 33 3:66 7
Solder for silver, soft	13 00	7 00	.....	.....	.....	Ag 80; see also "Silver solder"
Sorel's alloy	1 00	98 00	.....	.....	.....	Fe 1 0; also 10:80:10
Spectrum metal	64 00	.....	32 00	.....	.....	Ni 4.00
Spectrum metal, Cu <sub>4</sub> Sn	68 25	.....	31 75	.....	Sb	
Spectrum metal, Chinese	80 80	.....	10 70	.....	8 50	
Spectrum metal, Chinese	80 80	.....	.....	9 10	8 80	
Spectrum metal, English	66 60	.....	33 40	.....	.....	
Spauter (hard zinc)	2 00	90 00	.....	.....	8 00	Cr 12; Si 5; C 0 45; bal. Fe
Stainless (Armstrong)	.....	.....	.....	.....	.....	Cr 13; Mn 0 3; C 0 3; bal. Fe
Stainless (Brearly)	.....	.....	.....	.....	.....	

Stanniol	1 00	96 20	2 40	Sb	Ni 0 30 Fe 0 10
Statuary alloy (small cast)	...	75 00	5 00	20 00	See also "Bronze, statuary"
Stellite	...	...	...	...	Cr 25; Co 75
Stellite	...	...	...	...	Cr 25; Co 70; W 5; also 15:60:25
Stellite	...	...	...	...	Cr 15; Co 55; W 25; Mo 5
Stellite	...	...	...	...	Cr 13 2; Co 60 8; Fe 0 5; Mo 24 1
Stellite	...	...	...	...	Cr 20-23; Co 55; Fe 3-5; W 15-20; C 1 5-4 0
Stellite	...	...	...	...	Cr 26 4; Co 34 5; Fe 10; W 12 5 Mo 9 5; C 1 8
Sterlin	68 52	12 84	0 76	...	Cr 33 6; Co 55 6; W 9 2; C 1 5
Sterline	68 00	13 25	...	...	Ni 17 88; a. Ni-Ag for forks, etc.
Stereotype metal-English	...	...	4 50 32 50	Sb 13 00	Ni 18 00; Fe 0 75
Stereotype metal	...	...	6 00 82 00	12 00	Also 3 2; 82 0; 14 8
Stereotype metal	...	...	4 00 75 00	20 00	Also 7 0; 70 0; 23 0
Stereotype metal	...	...	17 00 67 00	16 00	Also 60 0; 35 0; 5 0
Stirling brass	66 20	33 10	...	...	Fe 0 70
Stirling brass, cast	66 20	31 00	0 02	...	Fe 0 66
Superbronze	56 80	37 50	...	...	Al 1 2; Fe 1 3; Mn 3 2
Superbronze	68 90	20 90	...	...	Al 5 1; Fe 2 0; Mn 3 0
Susini	1 50	0 50	...	...	Mn 1-3; bal Al
Susini	2 50	1 00	...	...	Mn 1-5; bal Al
Susini	4 50	1 50	...	...	Mn 2-8; bal Al
Sterro	60 00	38 20	...	...	Fe 1 8
Sterro	55 50	42 00	...	...	Fe 2 5; Also 55 33 41 8 4 66
Sterro	55 00	42 40	0 83	...	Fe 1 8
Suhler's white copper	40 40	25 40	2 60	...	Ni 31 60
T metal (Al alloy)	0 10	...	...	...	Mg 3 8; Fe 0 5; Si 0 5; bal Al
Talmi gold	90 00	8 92	...	...	Au 0 91
Talmi gold	86 40	12 20	1 10	Sb	Fe 0 3
Tandem	...	...	5 90 77 70	16 80	Fe 83 50; Si 15 0; C 1 0
Tantiron (acid resist)	...	...	...	...	See "Manganin"
Tarnac (resistance)	...	...	...	...	...
Tea lead	...	...	2 00 98 00	...	...
Telegraph bronze	80 00	7 50	5 00	7 50	...

ALLOYS. *Continued*

	Cu	Zn	Sn	Pb	Sb	
Tensile.	64.00	29.00	0.20	.....	.....	Al 3.1; Fe 1.2; Mn 2.5
Tensile, .....	67.00	24.00	.....	.....	.....	Al 4.4; Mn 3.8
Terne metal.	.....	.....	18.00	80.25	1.75	Al 10; Fe 0.98; Si 2.48
Tetmajer .....	86.10	.....	.....	.....	.....	Al 7.1; Fe 0.72; Si 2.72; also 93.3:4.6:0.89:0.98
Tetmajer .....	89.70	.....	.....	.....	.....	
Thurston's brass	55.00	44.50	0.50	.....	.....	See "Brass solder"
Thurston's solder.	.....	.....	.....	.....	.....	Ni 30.4; Fe 67.3; Mn 1.12
Tico (resistance)	1.10	.....	.....	.....	.....	Ag 33.33; Al 66.67
Tiers argent. ....	.....	.....	.....	.....	.....	
Tin foil .....	4.00	.....	87.50	8.00	0.50	
Tinzel .....	.....	.....	60.40	39.60	.....	
Tissier's brass....	97.00	2.00	0.50	.....	.....	
Tissier's brass....	97.00	2.00	.....	.....	.....	As 1.00
Tobin bronze .....	58.22	39.48	2.30	.....	.....	Also 59.39:2 and 60:38:2
Tombac, English .....	86.38	13.61	.....	.....	.....	Cast well
Tombac, French....	80.00	20.00	.....	.....	.....	Also 84:16; 88:12; 92:8
Tombac, Golden....	82.00	17.50	0.50	.....	.....	Also 80:17:3
Tombac, Oker .....	85.30	14.70	.....	.....	.....	The name covers a wide range of brasses
Tombac, Red Vienna	97.80	2.20	.....	.....	.....	
Tombac, common .....	71.50	28.50	.....	.....	.....	
Tophet (resistance)	.....	.....	.....	.....	.....	Ni 61; Cr 10; Fe 26; Mn 3
Toucas .....	35.75	7.14	7.14	7.14	7.13	Ni 28.56; Fe 7.14, Ornamental work
Tournay's brass .....	82.54	17.46	.....	.....	.....	
Tourin Leonard's metal	10.00	.....	90.00	.....	.....	
Trabic metal .....	.....	.....	87.50	.....	5.00	Ni 5.5; Bi 2, Resists organic acids
Trolley-wheel bronze.	92.00	6.00	.....	.....	.....	
Tuc-Tur (rod) .....	61.20	20.90	.....	.....	.....	Ni 17.6; Fe 0.3; Sheet is 58.6:28.5:12.5:0.3
Tungsten brass .....	60.00	22.00	.....	.....	.....	Ni 14; W 4
Tungsten brass .....	59.73	33.97	0.15	.....	.....	Al 2.8; W 2; Mn 0.7
Tungsten bronze....	90.00	.....	.....	.....	.....	W 10

Turbidum bronze.	48.00	46.45	0.50	0.10	Ni 2; Mn 1.75; Al 0.2; Fe 1; Propellers
Turbine wheel mixture	86.77	3.48	8.68	1.07	See also "Brass, turbine"
Turbiston's brass	55.00	41.00	91.40	7.62	Fe 0.84; Ni 2; Al 1; Mn 0.16
Tutania, cast	0.70	0.25	92.40	4.60	Plate is 2.7; 1.3; 90:6
Tutania, cast	2.50	0.32	92.40	4.60	Fe 0.13; See also "Britannia"
Tutania, English	2.70	1.30	80.00	16.00	See also "Britannia"
Tutenag.	45.70	36.96	.....	.....	Ni 17.33; Also 43.8:40.6:15.6
Tutenag.	44.00	16.00	.....	.....	Ni 40.0
Type metal, English	.....	.....	6.50	77.50	.....
Type metal, German	.....	.....	2.00	75.00	.....
Type metal, old Eng	2.00	.....	10.00	70.00	Also 17:9.1:70.0:19.5
Type metal, English	0.80	.....	12.00	63.20	Also 0.8:14.5:60.5:24.2
Type metal, German	.....	.....	35.00	60.00	Also 34.6:60:5.4 and 15:60:25
Type metal, common	.....	.....	10.00	60.00	Also 40:55.5:4.5
Type metal, Krupp's	4.70	.....	12.00	59.60	Ni 4.7; Bi 1
Type metal, English	1.00	.....	15.00	58.00	.....
Type metal, best	.....	.....	25.00	60.00	.....
Type metal, French	.....	.....	22.00	55.00	Also 15:55:30
Type writer Al-bronze	57.00	20.00	.....	.....	Ni 20; Al 3
Uchatius bronze	92.00	8.00	.....	.....	Ca Ba 1.5
Ucoloy	98.50	.....	.....	.....	.....
Uloony	65.00	.....	.....	35.00	.....
Valve bronze.	89.00	3.00	5.00	3.00	Also 83:4:7:6
Valve bronze, steam	88.00	2.00	10.00	.....	Also 85:6:9
Vanadium bronze, Vn-c	61.00	38.50	.....	.....	Va 0.5; also 70:29.5:0.5
Vaucher's alloy	.....	75.00	18.00	4.50	.....
Verilite.	2.50	.....	.....	.....	Mn 0.3; Fe 0.7; Si 0.4; bal. Al
Vesta (resistance)	.....	.....	.....	.....	A 28 per cent. nickel steel
Victor non-corros.	49.94	34.27	.....	.....	Fe 0.28; Ni 15.4; Al 0.11; Resists salt air
Wagner's forgings	50.66	19.31	.....	.....	Ni 13.18
Watch makers alloy	58.86	40.22	.....	1.90	An imitation gold
Wessel's silver	51.00	17.00	.....	.....	Ni 32.00
Warne's metal	.....	.....	37.00	.....	Ni 26; Bi 26; Co 11
White alloy	.....	.....	.....	.....	See "German silver"

Alloys. *Continued*

	Cu	Zn	Sn	Pb	Sb	
White brass...	3-6	29-32	65.00	..	..	Good automobile bearing metal Ni 12, a "German silver," English is Zn 76.2; Cu 5.6; Sn 17.5  Dutch is Cu 9.6; Sn 81.5; Sb 8.8
White copper	70.00	18.00	..	..	..	
White metal.	2.30	..	5.00	77.00	15.00	
White metal.	2.40	1.00	53.00	33.00	10.60	
White metal	3.30	..	49.10	33.90	13.60	
White metal, Hanover	5.60	..	86.80	..	7-60	
White metal, English	5.60	76.20	17.50	0.70	8.80	Al 98.00, W 0.05 Al 98.00, W 0.04 Mn 1.00, bal Al Bi 50, Cd 12.5; melts 60.5°C  Ni 60; bal Cr Mn, W—corrosion resistant Al 15 Mg 3.7; Al 93.5; also 4.5:4.5:91.0 Mg 7.1; Al 88.5; also 14.8:11.2:74.0 Al 83.0 Al 82.0; For cane and umbrella handles and the Al 60.0; like
White metal, Dutch	9.60	..	81.50	..	1.40	
Wolframum	0.36	..	..	..	0.44	
Wolframum	0.37	..	1.00	..	..	
W 0.33.	14.00	..	12.50	25.00	..	
Wood's metal	..	..	..	..	..	Zamium Zelco Zimalium Zimalium Zisum.. Zisum.. Zisum.. Ziskon.....
White metal, English	5.60	76.20	17.50	0.70	8.80	
White metal, Dutch	9.60	..	81.50	..	1.40	
Wolframum	0.36	..	..	..	0.44	
Wolframum	0.37	..	1.00	..	..	
W 0.33.	14.00	..	12.50	25.00	..	
Wood's metal	..	..	..	..	..	
Zamium	..	..	..	..	..	
Zelco	2.00	83.00	..	..	..	
Zimalium	..	2.80	..	..	..	
Zimalium	..	4.40	..	..	..	
Zisum..	1.00	15.00	1.00	..	..	
Zisum..	3.00	15.00	..	..	..	
Ziskon.....	..	40.00	..	..	..	



WIRE AND SHEET METAL GAGES COMPARED<sup>1</sup>

Number of gage	Birmingham or Stub's iron wire gage, inch	American or Brown & Sharpe's gage, inch	Roebbling's and Washburn & Moen's gage, inch	Stub's steel wire gage, inch	British Imperial Standard wire gage, inch	Legal standard since Mar. 1, 1884, mm.	U. S. sheet and plate gage, inch	Number of gage
0000000			0.49		0.500	12.7	0.500	36
0000000			0.46		0.464	11.78	0.469	36
000000			0.43		0.432	10.97	0.438	36
00000	0.454	0.46	0.393		0.400	10.16	0.406	36
0000	0.425	0.40964	0.362		0.372	9.45	0.375	36
000	0.380	0.3648	0.331		0.348	8.84	0.344	36
00	0.340	0.32486	0.307		0.324	8.23	0.313	0
1	0.300	0.2893	0.283	0.227	0.300	7.62	0.281	1
2	0.284	0.25763	0.263	0.219	0.276	7.01	0.266	2
3	0.269	0.22942	0.244	0.212	0.252	6.40	0.250	3
4	0.238	0.20431	0.225	0.207	0.232	5.89	0.234	4
5	0.220	0.18194	0.207	0.204	0.212	5.38	0.219	5
6	0.203	0.16202	0.192	0.201	0.192	4.88	0.203	6
7	0.180	0.14428	0.177	0.199	0.176	4.47	0.188	7
8	0.165	0.12849	0.162	0.197	0.160	4.06	0.176	8
9	0.148	0.11443	0.148	0.194	0.144	3.66	0.156	9
10	0.134	0.10189	0.135	0.191	0.128	3.25	0.141	10
11	0.120	0.09074	0.120	0.188	0.116	2.95	0.125	11
12	0.109	0.08081	0.105	0.185	0.104	2.64	0.109	12
13	0.095	0.07196	0.092	0.182	0.092	2.34	0.094	13
14	0.083	0.06408	0.080	0.180	0.080	2.03	0.078	14
15	0.072	0.05707	0.072	0.178	0.072	1.83	0.070	15
16	0.065	0.05082	0.063	0.175	0.064	1.63	0.0625	16
17	0.058	0.04526	0.054	0.172	0.056	1.42	0.0563	17
18	0.049	0.04030	0.047	0.168	0.048	1.22	0.0500	18
19	0.042	0.03589	0.041	0.164	0.040	1.02	0.0438	19
20	0.035	0.03196	0.035	0.161	0.036	0.91	0.0375	20
21	0.032	0.02846	0.032	0.157	0.032	0.81	0.0344	21
22	0.028	0.02535	0.028	0.155	0.028	0.71	0.0313	22
23	0.025	0.02257	0.025	0.153	0.024	0.61	0.0281	23
24	0.022	0.02010	0.023	0.151	0.022	0.56	0.0250	24
25	0.020	0.01790	0.020	0.148	0.020	0.51	0.0219	25
26	0.018	0.01594	0.018	0.146	0.018	0.46	0.0188	26
27	0.016	0.01419	0.017	0.143	0.0164	0.42	0.0172	27
28	0.014	0.01264	0.016	0.139	0.0148	0.38	0.0156	28
29	0.013	0.01126	0.015	0.134	0.0136	0.36	0.0141	29
30	0.012	0.01002	0.014	0.127	0.0124	0.31	0.0125	30
31	0.010	0.00893	0.013	0.120	0.0116	0.29	0.0109	31
32	0.009	0.00795	0.013	0.115	0.0108	0.27	0.0101	32
33	0.008	0.00708	0.011	0.112	0.0100	0.25	0.0094	33
34	0.007	0.00630	0.010	0.110	0.0092	0.23	0.0086	34
35	0.005	0.00561	0.0095	0.108	0.0084	0.21	0.0078	35
36	0.004	0.00500	0.0090	0.106	0.0076	0.19	0.0070	36
37		0.00445	0.0085	0.103	0.0068	0.17	0.0066	37
38		0.00396	0.080	0.101	0.0060	0.15	0.0063	38
39		0.00353	0.0075	0.099	0.0052	0.13		39
40		0.00314	0.007	0.097	0.0048	0.12		40
41				0.095	0.0044	0.11		41
42				0.092	0.0040	0.10		42
43				0.088	0.0036	0.09		43
44				0.085	0.0032	0.08		44
45				0.081	0.0028	0.07		45
46				0.079	0.0024	0.06		46
47				0.077	0.0020	0.05		47
48				0.075	0.0016	0.04		48
49				0.072	0.0012	0.03		49
50				0.069	0.0010	0.025		50

<sup>1</sup> From KENT'S "Mechanical Engineer's Pocket Book," 8th Edition, p. 30; and "American Machinist," p. 931, Dec. 5, 1912. The moral of the above table is to specify wire by mills and not by gages. See p. 684 for sheet-zinc gage.

(Continued from page 613)

The temperature coefficient of electrical resistance is usually much less than for either component, and is usually at a minimum at the composition of highest specific resistance.

When two metals form a continuous series of solid solutions, the hardness of each is increased by the other, the alloy of maximum hardness usually containing about 50 atoms per cent. of each metal. In the case of limited solubility, the tendency is for the hardness to increase with the concentration of the solute in solution.<sup>1</sup>

In general, the plasticity decreases by the presence of a solute in solid solution.

NOTE.—The "solvent" in an alloy that is a solid solution is that metal whose space lattice persists in the solid solution. The "solute" is the other. This criterion fails when two metals having the same type of space-lattice form a continuous series of solid solutions. The solvent may then be arbitrarily defined as that element the concentration of which in the solution exceeds 50 atoms per cent.

**Gaseous Alloys** are in general stable only at low temperatures and pressures. This is shown, according to H. von Wartenberg (*Journ. Soc. Chem. Ind.*, Nov. 16, 1914), by a consideration of NERNST's heat theorem and TROUTON's rule. A determination of its heat of formation showed that  $\text{MgZn}_2$  exists at  $600^\circ\text{C}$ ., and vapor density determinations that it is dissociated at  $1300^\circ\text{C}$ . The vapor tensions of sodium and of  $\text{Na}_2\text{Hg}$  were measured at  $444^\circ\text{C}$ ., and the stability of  $\text{Na}_2\text{Hg}$  at  $380^\circ$  and  $444^\circ\text{C}$ . demonstrated by distillation.

### Unstable Alloys<sup>2</sup>

The following metals do not form stable alloys within the limits mentioned, *i.e.*, if a mixture containing percentages of the materials lying between the critical points is heated, there may be (though not always) an alloy produced at the time, but there will be segregation on standing.

Temperature		Zinc-lead alloys	
650°C.	Between.....	$\left\{ \begin{array}{l} \text{Pb} = 98.76 \\ \text{Zn} = 1.24 \end{array} \right.$	and $\left\{ \begin{array}{l} \text{Pb} = 1.14 \\ \text{Zn} = 98.86 \end{array} \right.$
800°C.	Between.....	$\left\{ \begin{array}{l} \text{Pb} = 98.70 \\ \text{Zn} = 1.30 \end{array} \right.$	and $\left\{ \begin{array}{l} \text{Pb} = 1.57 \\ \text{Zn} = 98.43 \end{array} \right.$
		Bismuth-zinc alloys	
650°C.	Between.....	$\left\{ \begin{array}{l} \text{Bi} = 85.72 \\ \text{Zn} = 14.28 \end{array} \right.$	and $\left\{ \begin{array}{l} \text{Bi} = 2.32 \\ \text{Zn} = 97.68 \end{array} \right.$
750°C.	Between.....	$\left\{ \begin{array}{l} \text{Bi} = 84.82 \\ \text{Zn} = 15.18 \end{array} \right.$	and $\left\{ \begin{array}{l} \text{Bi} = 2.47 \\ \text{Zn} = 97.53 \end{array} \right.$
800°C.	Between.....	$\left\{ \begin{array}{l} \text{Bi} = 84.17 \\ \text{Zn} = 15.83 \end{array} \right.$	and $\left\{ \begin{array}{l} \text{Bi} = 2.52 \\ \text{Zn} = 97.48 \end{array} \right.$

<sup>1</sup> JEFFRIES AND ARCHER, *Chem. Met. Eng.*, Nov. 26, 1923.

<sup>2</sup> ROBERTS-AUSTEN, "Introduction to the Study of Metallurgy"

Temperature		Lead-aluminum alloys	
800°C.	Between.....	$\left\{ \begin{array}{l} \text{Pb} = 99.93 \\ \text{Al} = 0.07 \end{array} \right.$	and $\left\{ \begin{array}{l} \text{Pb} = 1.91 \\ \text{Al} = 98.09 \end{array} \right.$
		Bismuth-aluminum alloys	
800°C.	Between.....	$\left\{ \begin{array}{l} \text{Bi} = 99.72 \\ \text{Al} = 0.28 \end{array} \right.$	and $\left\{ \begin{array}{l} \text{Bi} = 2.02 \\ \text{Al} = 97.98 \end{array} \right.$
		Cadmium-aluminum alloys	
750°C.	Between.....	$\left\{ \begin{array}{l} \text{Cd} = 99.78 \\ \text{Al} = 0.22 \end{array} \right.$	and $\left\{ \begin{array}{l} \text{Cd} = 3.39 \\ \text{Al} = 96.61 \end{array} \right.$

## Alloys

**Admiralty Metal**, Government bronze, gun metal or Navy Dept. composition is about 88 Cu, 10 Sn, and 2 Zn. According to STALEY and KARR (*Bull. A.I.M.E.*, Sept. 1919) the most satisfactory alloy of about this composition is 90 Cu, 6.5 Sn, 0.5 Pb, 3 Zn. Proportional limit  $12,200 \pm 650$  lb. per sq. in.; tensile strength,  $40,700 \pm 1500$  lb. per sq. in.; elongation in 2 in.,  $37.6 \pm 6.4$  per cent.; and reduction in area  $34.1 \pm 4.5$  per cent. Lead over  $\frac{1}{2}$  per cent. Pb substituted for zinc or tin has undesirable effects as does over 2 per cent. of Zn substituted for tin. The pouring temperature should be about 1100°C.

**Adnic (Admiralty Nickel)**.—70 per cent. Cu; 29 Ni; 1 per cent. Sn. Especially valuable for diaphragms. Ultimate tensile, 69,000 — 131,000 lb. per sq. in. Good resistance to caustic soda, salt spray, sulphuric acid, and solutions containing chlorine.

PHYSICAL PROPERTIES OF ADNIC  
( $\frac{1}{2}$  In. Hard Rod)

Modulus of elasticity, lb. per sq. in. ....	21,300,000
Elastic limit, lb. per sq. in. ....	85,000
Yield point, lb. per sq. in. ....	107,000
Tensile strength, lb. per sq. in. ....	113,200
Elongation in 2 in., per cent. ....	10
Reduction in area, per cent. ....	56½
Scleroscopic hardness (U. Hammer) ....	31
Coefficient of thermal expansion, per °C. ....	0.0000163
Electrical resistivity at 20°C., ohms. ....	256
Melting point, °C. ....	1,205
Density at 20°C. (68°F.), lb. per cu. in. ....	0.3214

PHYSICAL PROPERTIES OF ADNIC  
1 In. Hot-rolled Hex. Rod

Tensile strength, lb. per sq. in. ....	64,500
Elastic limit, lb. per sq. in. ....	30,500
Yield-point, lb. per sq. in. ....	35,600
Reduction in area on $\frac{1}{2}$ in. dia. cross-section, per cent. ....	72.2
Elongation in 2 in., per cent. ....	46

**Alcumite**.—A non-ferrous alloy, for use in the construction of equipment has been placed on the market by the Duriron

**Co.** This alloy is said to be resistant to sulphuric acid under 60° Bé., sulphurous acid, phosphoric acid, weak solutions of hydrochloric acid and a large number of sulphates and chlorides, fatty acids and fruit juices.

The melting point of this alloy is approximately 1900°F., and up to 1600° it remains tough, strong and ductile. The ultimate tensile strength of the rolled material is about 100,000 lb. per sq. in., the ductility depending on the heat treatment applied. Castings have a tensile strength of approximately 75,000 lb. per sq. in. with about 25 per cent. elongation. The metal is said to machine readily. Composition, Cu 87.5; Al 7.5; Fe 3.3; bal Ni.

**Allegheny Metal.**—A product of the Allegheny Steel Co. apparently a chromium-steel or iron, but no analyses are given.

**Alpac.**—A high-silicon aluminum alloy, invented by Dr. Pacz. The high-silicon alloys have not as high tensile strength as have duralumin and some of the Al:Cu alloys but they have a low contraction on freezing and can be used to produce castings that cannot be made in other materials.

**Aluminum.**—Aluminum containing 0.05 to 0.20 per cent. of Ce is more resistant to corrosion than aluminum itself.

Aluminum alloys for automobile work (Society of Automotive Engineers Specifications 30, 31, 32). Where a light, tough alloy is needed, Al, not under 90 per cent., Cu from 7.0 to 8.5 per cent. Total impurities shall not exceed 1.7 per cent., of which not over 0.2 per cent. shall be zinc. No other impurities are allowable than C, Si, Fe, Zn and Mn. For a mixture possessing strength and closeness of grain that can be cast solid and free from blowholes, Al, not under 80 per cent.; Zn, not over 15 per cent.; Cu, 2-3 per cent.; Mn, not over 0.4 per cent. Total impurities shall not exceed 1.65 per cent., of which not over 0.5 per cent. shall be Si, nor over 1.0 per cent. Fe, nor over 0.15 per cent. Pb. For a cheap casting not subject to great strains (flat plates, foot-boards, etc.) use Al, 65 per cent.; Zn, 33 per cent.

Aluminum Alloys for Zeppelin Construction.—Angle brackets, Al, 90.27 per cent.; Zn, 7.8 per cent.; Cu, 0.73 per cent.; traces Fe, Si, Mn, Sn. Channel sections, 88.68 per cent. Al; 9.1 per cent. Zn, other elements as in angle brackets. The braces are commercial aluminum.

Hard Aluminum for Cooking Utensils, Mn, 1.2-1.5 per cent. "Alclad" consists of pure aluminum rolled on to aluminum alloy sheets, the latter to give strength, the former to give protection against corrosion.

**Ambrac.**—A white alloy, approximately 75 Cu, 20 Ni, 5 Zn; a product of the American Brass Co., said to be adapted to hot rolling and forging as well as to cold working. It is said to outlast all other materials for jig screens on sulphide ores. The tensile strength runs from 50,000 lb. per sq. in. in soft sheet metal to 84,000 lb. in hard-rolled. The yield point varies from 24,000 lb. per sq. in. in soft sheet to 65,000 lb. in light rolled rod.

## PHYSICAL PROPERTIES OF AMBRAC

(½ In. Hard Rod)

Modulus of elasticity, lb. per sq. in. . . . .	19,000,000
Elastic limit, lb. per sq. in. . . . .	75,000
Tensile strength, lb. per sq. in. . . . .	80,000
Elongation in 2 in., per cent. . . . .	12
Electrical resistivity at 20°C., ohms . . . . .	172
Melting point, deg. C. . . . .	1,150
Coefficient of thermal expansion, per deg. C. . . . .	0.0000164
Coefficient of thermal expansion, per deg. F. . . . .	0.0000091
Density at 20°C. (68°F.), lb. per cu. in. . . . .	0.3194

Ascoloy.—A 14 per cent. chrome steel, marketed by the Allegheny Steel Co.

Aluminum-Zinc Alloy.—Macadamum—strong but light castings. Patented alloy. Composition unknown.

Auer Metal.—35 per cent. Fe and 65 per cent. of the metal obtained by reducing the cerium earths (Misch metal, *q.v.*).

Bismuth Alloys.—Bi, 3; Pb, 10; Sn, 5. Sticks to glass, melts at 170°C. See also "fusible alloys" in table, p. 633.

Barberite.—A high-copper bronze, containing Ni and Si. Said to be highly resistant to sulphuric acid. Patented by Barber Asphalt Co.

Biakmetal.—A variety of different alloys grouped under the single trade name. Biak No. 2 is an ordinary 60:40 brass containing a little manganese. Biak No. 3 is the same with Ni instead of Mn. Biak No. 4 is a high red brass containing both Ni and Mn. Biak No. 6, is a high-aluminum: zinc: copper alloy, containing a little silicon. Biak Nos. 9 and 19 are high-zinc: aluminum: copper alloys such as have come into use in France for extruding purposes and as bearing metals.

Britannia.—Analyses are given in the main table. The researches of B. EGEBERG and H. B. SMITH show that rolling softens and weakens Britannia, and where strength is important, the material should be cast in as thin sections as possible.

Cadmium Solders.—The alloy Pb 32, Sn 50, Cd 18 is a eutectic with a melting point of 145°C., and is a desirable low melting point solder. (Pb 50, Sn 50 solidifies over the range 210–181°C.)

Calorized Metal.—See Insuluminum, below.

Carboloy.—Tungsten carbide. See p. 672.

Cerium Alloys.—The iron-cerium alloys will be found described at length under "pyrophoric alloys." Cerium-platinum alloys have also been recommended for this purpose, while those with zinc and boron, because of the low temperature of the spark are supposed to be especially good for igniting mine lamps. The cerium-mercury compounds are exceedingly explosive. The cerium-iron alloys are apparently definite compounds,  $CeFe_2$ ,  $Ce_2Fe_3$ ,  $Ce_2Fe_6$ .  $CeFe_6$  is highly oxidizable.

Chromium Alloys.—The chief chromium alloys in commercial use are chromax, nichrome and stellite, which see in table beginning p. 614. See also pp. 197 and 198.

The chromium-iron alloys are highly important from a corrosion resistance standpoint. They may be classed as: (1) stainless steels, containing sufficient carbon to confer hardening capacity, and requiring heat treatment for development of proper corrosion resistance; (2) mild stainless steels of lower carbon content, but possessing hardening capacity. Heat treatment desirable but not necessary for development of corrosion resistance; (3) stainless irons with over 16 per cent. Cr and low carbon; (4) chrome-irons, over 20 per cent. Cr.

The original stainless steel carried 0.30 per cent. C and 13 per cent. Cr. The newer steels carry even up to 1.5 per cent. C and 18-20 per cent. Cr. They harden by air cooling, are very hard but lack ductility and toughness.

They do not soften perceptibly up to 950-1000°F. Low carbon: Carpaloy 2; Crucible Stainless A; Firth-Sterling type A; high carbon: Midvale Diamond; Firth-Sterling B; Crucible Stainless B; Dehli Hard; Neva-Stain.

Mild Steels.—The composition is narrowly restricted to 12, 14 or 15 per cent. Cr, with C less than 0.12—rarely 0.18-0.20 where greater hardness is desirable. It resists nitric acid, is very tough and strong, and resists scaling up to 1500-1600°F. Brinells of 352-444 are easily obtainable by airhardening. This makes it less desirable for riveting and welding than true stainless irons unless the work will admit of subsequent annealing. Enduro S; Crucible Stainless 12; Ascoloy 33; Firth-Sterling T; Carpaloy 1; Uniloy 1409.

Stainless Irons.—16-20 per cent. Cr; C under 0.12 per cent. No hardening capacity (maximum Brinell about 200); excellent corrosion resistance. Very resistant to chemical corrosion. High silicon (around 1 per cent.) increases resistance to acids and to scaling; decreases resistance to alkalis. Addition of copper increases resistance to halogens. Excessive temperatures must be avoided because of grain growth which cannot be removed except by mechanical working. Welds in stainless irons are likely to be brittle. (Enduro A; Defirust; Ascoloy 66; Uniloy 1609.)

The iron-chromium alloys are of the utmost importance in plants for nitric-acid manufacture by oxidation of ammonia and they resist mild organic acids well.

Chrome-irons.—Cr minimum 20 per cent. Without hardening capacity. For maximum wear, C should be from 2.25-2.75 per cent. Maximum resistance to scaling at about 22 per cent. Cr. Can be used for long periods at 2100°F., but if stresses are heavy, chrome-nickels with added silicon or tungsten are preferable (*Chem. Met. Eng.*, September, 1929).

Cimet.—Chrome irons containing about 48 per cent. Cr. A corrosion-resistant alloy, particularly resistant to fruit juices and to hot sulphur-bearing gases.

Cobalt Alloys.—Cobalt in brass acts much as does nickel, in spite of their different influence in steel.

An alloy of tungsten carbide and cobalt is the hardest alloy known. It will scratch sapphire. See also "Concl."

**Cobalt-Tin** (40 Co, 60 Sn to 60 Co, 40 Sn).—Very resistant to acids, but too brittle for ordinary purposes.

**Cochrome**.—A substitute for nichrome, about 60 per cent. Co, 12 per cent. Cr, 24 per cent. Fe, 2 per cent. Mn.

**Conel**.—Cobalt and nickel with ferro-tungsten. Exact proportions unknown. Grows harder when hot—a unique property.

**Copper-cadmium Alloy**.—Copper with  $1\frac{1}{4}$  per cent. Cd has a tensile of about 80,000 lb. per sq. in. and 89 per cent. conductivity.

**Coinage Alloys**.—United States gold and silver coins are 900 fine. The Irish 3d. and 6d. pieces, and the Canadian 5-cent piece are pure nickel. Swedish bronze coins are 95 Cu, 4 Sn 1 Zn. Danish minor coins are 92 Cu, 6 Al, 4 Ni and 75 Cu, 25 Ni. The United States 5-cent piece is 75 Cu, 25 Ni.

**Constantan**.—Cu, 54.15 per cent.; Ni, 43.70; Fe, 0.435; Co, 1.34; Cr, 0.033; S, 0.0237; P, 0.0010; Si, 0.098; C, 0.14 per cent. It should give an e.m.f. of 47.40 millivolts against pure iron at 1500°F., with a cold-junction temperature of 0°F. (Bash, *Bull. A.I.M.E.*, September, 1919, p. 2409.) See also table, p. 198, for other alloys sold under this name. •

**Copper-manganese Alloys**.—For turbine blades, 95 per cent. Cu, 5 per cent. Mn; for locomotive fire boxes and stays, Mn not over 4 per cent.; manganin, 12–14 per cent. Mn, 4 per cent. Ni, balance Cu; U. S. Navy casting alloy, 2 per cent. Mn, 3 per cent. Cu, 95 per cent. Al.

**Corson's Hardened Copper**.—Cu, 95 per cent.; Ni, 4 per cent.; Si, 1 per cent. Is ductile and easily cold worked if quenched from temperatures above 750°C.

**Duraloy**.—A chrome iron, 16–18 or 27–30 Cr. Corrosion resistant.

**Duralumin**.—MERICA, WALTEBERG and SCOTT recommend a composition for duralumin of: Cu, 3 to 4.5 per cent.; Mg, 0.4 to 1.0 per cent.; Mn, 0 to 0.7 per cent.; 99 per cent. Al (remainder). The heat treatment that they recommend is to preheat as close to 520°C. as furnace limitations will allow, but not above 520°C., holding at this temperature for 10 to 20 min. and quenched preferably in boiling water. For most purposes hardening is then best produced by ageing for about 5 days at 100°C. If higher proportional limits and lower ductility are desired than can be obtained in this way, age from 2 to 4 days at 150°C. Duralumin should be rolled at 450°C. (*Bull. A.I.M.E.*, June, 1919, p. 913).

**Durimet**.—A nickel-silicon steel containing copper, put out by the Duriron Co. It may be welded, machined, cast, rolled, forged and fabricated. It has now been used for pickling tanks, giving an indicated life of 5 to 7 years.

It is very resistant to sulphuric acid and samples subjected to constant agitation showed indicated penetrations as follows:

Sulphuric acid, 2.5 per cent. ....	0 62	0.043
Sulphuric acid, 10 per cent. ....	0 35	0.024
Sulphuric acid, 10 per cent. cold .....	0 35	0.024
Sulphuric acid, 25 per cent. ....	0 31	0.021
Sulphuric acid, 50 per cent. ....	0 49	0.034
Sulphuric acid, 60 per cent. cold .....	0 09	0.006
Sulphuric acid, 95 per cent. cold .....	0 57	0.039

**Elianite.**—A patented composition; withstands acids and halogens; melts at 1250°C. Probably a ferro-silicon.

**Elinvar.**—Ni 36, Cr 12, Fe 52. Has low thermal expansivity and an invariable modulus of elasticity.

**Enduro.**—17-19 Cr; 8-9 Ni; Fe about 73. Acid-resisting and maintains strength at high temperatures (Central Alloy Steel Co.).

**Everbrite.**—A cupronickel alloy made by Curtis Bay Copper & Iron Works, Baltimore, Md. It is resistant to organic acids, except acetic and to alkalis. Hydrochloric acid attacks it, sulphuric acid less so. Most salts are without much action.

**Everdur.**—Cu, 94.4 per cent.; Si, 4.5 per cent.; Mn, 1.1 per cent. if the material is to be used for castings; Cu, 96.0 per cent.; Si, 3 per cent.; Mn 1.0 per cent. if the material is to be rolled or drawn. It is corrosion resistant, particularly to hydrochloric acid and the chlorides. Patented by SCHÜTTE & KOERTING.

For comparative purposes the tensile strength of  $\frac{3}{8}$ -in. hot-rolled Everdur rod at elevated temperatures, determined by U. S. Bureau of Standards, is given below.

Temp, deg. F.	Ultimate lb. per sq. in.	Elongation in 2 in. gage length, per cent.	Reduction of area, per cent
80	72,650	43.5	51.0
500	60,200	33.0	67.4
750	35,930	25.5	69.4
1,000	14,480	18.0	71.4

Thermal conductivity, B.t.u. per sq. ft. per hr., 1 in.

thickness..... 72.6

Electrical resistivity, ohms per cir. mil-foot ..... 186

Coefficient of linear expansion, per deg. C.. ..... 0.0000170

**Ferro-alloys.**—The following brief description of the ferro-alloys chiefly used is condensed from *The Mining Journal*, Feb. 20, 1915. These alloys may be grouped in two divisions, those used as alloying materials and those used as deoxidizers.

**Ferro-manganese.**—The alloy is chiefly used as an 80 per cent. ingredient, and is employed in the Thomas, Martin, and electro-steel furnaces. The addition varies from 0.5 to 1.5 per cent. of the weight of the steel. This product is produced



at present almost exclusively in the ordinary mass furnaces, and so far as ferro-manganese is concerned, the electric smelter has not hitherto been able to compete, the reason being simply that manganese is a comparatively easily smelted metal, and with the high temperature to be looked for in the electric furnace the metal would be apt to get overheated, with the risk of volatilization. In applying ferro-manganese, unlike ferro-silicon, it is heated and added to the steel bath, preferably in a molten condition. Apart from its deoxidizing effect, ferro-manganese serves directly to increase the toughness of the iron to a considerable degree. As silicon and manganese together combine in a direct deoxidizing and toughening effect, they are often required to be delivered in the following combinations—namely: Ferro-silicon—of about 25 per cent. Si content is usually added in the proportion of 0.3–1 per cent. of the body of the steel to be treated. It has a quieting effect and is usually placed in the converter in the quantity desired. Ferro-manganese-silicon—in various content percentages. The usual association for this product is about 70 per cent. manganese and about 25 per cent. silicon. Silicon-aluminum—(usually known in commerce as “Sical”) is produced with about 52 per cent. Si and about 27 per cent. Al. Calcium-silicide—has usually about 27 per cent. Ca and about 64 per cent. Si. Calcium-Silicon-Aluminum.—All these last associations (ferro-manganese silicon, silicon-aluminum, calcium-silicide, and calcium-silicon-aluminum) are employed in the Martin and electro-steel works. The quantity added is around 1 per cent. of the steel bath's weight. The above percentages of the several metals are the values usually delivered, though there are a number of variations, and the several steel works often use their own prescriptions for these combinations. Ferro-Chrome.—The above alloy was formerly produced entirely in mass furnaces (where, indeed, it is to a certain extent produced at the present time). Owing to similar conditions to those stated above in reference to the mass furnace's connection with the ferro-silicon industry, one must here content oneself with a lower product percentage with a relatively high carbon content. Lately the demand for a high per cent. alloy is specially referable to ferro-chrome, from which one may practically take it for granted that the greater part of the ferro-chrome at present employed in the steel industry is produced in electric smelters. The article is delivered, according to the requirements of the steel works, with various carbon contents, from  $\frac{1}{2}$  per cent. up to 10 per cent. C., and around 65 per cent. Cr. Ferro-chrome is employed as an addition to iron in Martin, electro-steel, and crucible furnaces to increase the hardness of the iron. The addition is up to 6 per cent. of the weight of the steel under treatment. Ferro-wolfram—is added to the steel bath in quantities up to 24 per cent., and increases the cutting capacity of the steel. Ferro-molybdenum—operates in the same manner as wolfram, though added in lesser quantities. The maximum addition is about 2 per cent. It is used for special shop tools. Ferro-

cobalt—has also recently been employed as an added ingredient in the manufacture of steel shop tools. The addition ranges up to about 4 per cent. Ferro-vanadium.—Besides operating as a deoxidizing medium this alloy has a direct effect on the steel bath, in that it to an unusually high degree increases the toughness of the steel. It is employed in the Martin furnace up to 0.2 per cent., and in electro and crucible furnaces up to 2 per cent. Ferro-titanium—has lately been entirely employed as a deoxidizing medium, especially in America in Martin furnaces, and in England in crucible furnaces. The main consumption is confined to ferro-silicon and ferro-manganese. As regards the second group—ferro-alloys as a pure deoxidizing medium—we have a number of combinations, of which the most important are ferro-nickel, ferro-chrome, ferro-wolfram, ferro-molybdenum ferro-cobalt, ferro-vanadium, ferro-manganese, and ferro-silicon. Ferro-nickel.—Pure nickel is used to a large extent as an addition to the steel bath. Lately, however, there have been requests from the steel works that this nickel be added to the steel bath in the form of ferro-nickel. As a chief reason for this, it may be mentioned that nickel in the large steel works is often liable to be stolen. If, therefore, the nickel is previously combined with a certain quantity of iron, the metal will be of no value to other than just that particular steel works, and thus robbery is obviated. See also iron-nickel alloys, p. 666.

Genelite.—A synthetic brass formed by reducing oxides of tin and copper with an excess of graphite which remains behind. Used as a bearing metal. Very low tensile, but good compressive strength.

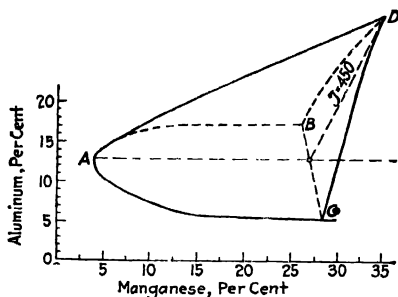
Hascrome.—A manganese-chrome-iron welding rod made by the Haynes Stellite Co. It is self hardening. Brinell, 240 to 500.

Hastelloy.—A nickel-molybdenum-iron alloy made by the Haynes Stellite Co., and particularly resistant to hydrochloric acid.

Heusler Alloys.—Copper alloys containing from 7 to 11 per cent. aluminum and from 20 to 10 per cent. manganese can be hot-rolled with the utmost ease and possess in a general way all mechanical properties, advantages, and disadvantages of the duplex aluminum bronzes. They can be heat treated in the same way, by quenching from a high temperature and drawing at a lower one, and rather strong alloys with 100,000 lb. tensile strength, 80,000 lb. yield point and 10 per cent. elongation in 2 in. are so produced. With ternary manganese-aluminum bronzes, just as with the binary duplex aluminum bronzes, quenching brings the material to a state of a high hardness and gives it a martensitic structure. A subsequent drawing somewhere around 600°C. eliminates the internal stresses inherent to the martensitic form with its 270 Brinell and no ductility at all, and a second quenching produces an alloy that is strong and fairly ductile.

When the drawing is done within 600° to 700°C. and is followed by quenching, certain ternary copper-manganese-

aluminum alloys acquire a considerable magnetic permeability besides good mechanical properties. Alloys so heat treated are called HEUSLER bronzes. Undoubtedly HEUSLER initially studied the magnetic properties exclusively, and these, though theoretically interesting, were of no practical use. HEUSLER's further investigations resulted in the development of ternary alloys combining the magnetic properties with a superior strength. The magnetic properties of HEUSLER's alloys are believed to be due to the presence of the compound  $Mn_3Al$ , magnetic in itself and imparting its inherent magnetism almost completely to the beta phase of the aluminum bronze.<sup>1</sup>



Heusler alloy diagram.

**High-speed Cutting Alloy.**—55 per cent. Co; 15 per cent. Cr; 25 per cent. W; 5 per cent. Mo retains its edge even at red heat. The W can be increased to 40 per cent. giving it still higher temperature resistance. Over 40 per cent. W gives too brittle an alloy for lathe tools.

A metallographic study of uranium high-speed steels indicates that the uranium tends to promote the formation of complex carbides. The cutting efficiency and the property of "red hardness" of high-speed steels is wholly dependent upon complex carbides.

High-speed Steel.—C, 0.45–0.85 per cent.; Si, tr.–0.20 per cent.; Mn, 0.10–0.50 per cent.; W, 8 to 18 per cent. Z Cr, 2.50–6.5 per cent.; Mo, 0–2.50 per cent.; V, 0–1.5 per cent.; Co, 0–5 per cent.

High-speed Steel (Beth. Steel Co., Paris Exposition).—C, 0.6 per cent.; Mn, 0.2 per cent.; Si, 0.1 per cent.; Cr, 4 per cent., W, 18 per cent.

**Hydraulic Bronzes.**—The presence of very small proportions of aluminum makes castings porous throughout, although they look solid. Iron and antimony are also detrimental. For cocks, pistons, bushings, etc., S. D. SLEETH recommends Cu, 72.50 per cent.; Sn, 1.75 per cent.; Zn, 19.25 per cent.; Pb, 6.50 per cent., for alloys for high pressures, 3000 lb. per sq.

<sup>1</sup> M. G. CORSON: Cleveland meeting A I.M.E., 1927.

in. (See the general table, p. 638.) The bronzes Cu 82; Zn 4.75; Sn 7.50; Pb 5.75 and Cu 83; Zn 4; Sn 11.50; Pb 1.5 are difficult to roll, but extremely solid.

Inca Bronzes from Machu Picchu, Peru.—These were analyzed by FRANK G. MOONEY in the Sheffield Chemical Laboratory. Compositions are erratic, running from 86.03 Cu and 13.45 Sn up to 96.96 Cu and 2.11 Sn. This last specimen carried 0.81 per cent. Ag. An ax carried 0.87 per cent. Fe, 0.44 S (93.70 Cu, 5.01 Sn). Pure tin, pure silver, and pure copper were found at Machu Picchu, showing that tin was sometimes, at least, smelted separately.

Insuluminum.—The name of a metal patented by the General Electric Co. It consists of steel given a surface impregnation of aluminum. When exposed to air or gases containing oxygen, the surface oxidizes to alumina. The resulting composition will resist for an indefinite time the continued action of oxygen-bearing gases at 1000°C.

Invar.—Ni, 36 per cent.; C, 0.15, balance Fe. The coefficient of linear expansion over the ordinary range of temperatures is  $+0.0000025$  to  $-0.00000005$  per deg. C.

Iron-nickel alloys do not forge readily if at all, but manganese or titanium in amounts of 2 per cent. of the nickel give forgeable alloys. T. D. YENSEN, *Trans. A.I.M.E.*, January, 1920.)

THERMAL EXPANSIVITY OF IRON-NICKEL ALLOYS

Per cent. nickel	Mean coefficients of linear expansion $\times 10^6$	Per cent. nickel	Mean coefficients of linear expansions $\times 10^6$
0	10.354+0 00523t	44.4	8 508-0 00251t
5 0	10.529+0 00586t	48.7	9 901-0 00067t
19.0	11.427+0 00362t	50.7	9 824+0 00243t
26.2	13.103+0 02123t	53.2	10.045+0 00031t
27.9	11.288+0 02889t	70.3	11.890+0 00387t
28.7	10.387+0 03004t	100.0	12.661+0 00550t
30.4	4 570+0 01194t	12.2+1 Cr	11.714+0 00508t
31.4	3.395+0 00885t	16.8+1 Cr	11.436+0 00170t
34.6	1.373+0 00237t	16.2+2 5 Cr	19.496+0 00432t
35.6	0.877+0 00127t	21.3+3 Cr	18 180+0 00426t
37.3	3.457-0 00647t	34.8+1 5 Cr	3 580-0 00132t
39.4	5 357-0 00448t	35.7+1 7 Cr	3.373+0 00165t
43.6	7.992-0 00273t	36.4+0.9 Cr	4.433-0 00392t

Supplementing the above table, tables of the electrical and magnetic properties of iron-nickel alloys appear on pp. 668 and 669. Invar melts at 1425°C., has a density of 8.0 grams per cc. and an electrical resistivity of about 80 microhm-cm.

Ivanium.—A patented aluminum alloy (British). Melts at about 300°C.

Kromore.—85 per cent. Ni, 15 per cent. Cr. The specific resistance is 95.9 microhms per cm.<sup>3</sup> at 20°C. or 577 ohms per mil-foot at 20°C. The temperature coefficient is 0.000242

ohm per deg. C. per ohm at 20°C. or 0.000134 ohm per deg. F. This alloy resists oxidation to a high degree and is especially recommended when extreme conditions are to be encountered such as open type heating units. Begins to freeze at about 1438°C. (the eutectic Ni 42 per cent., Cr 58 per cent. melts at 1290°C.).

**Kunheim Metal.**—A pyrophoric alloy containing hydrides of the cerium earth metals with magnesium and aluminum.

**Leading-in Wire Alloy.**—46 per cent. Ni, 54 per cent. Fe, with a sheath of copper. Copper has a higher coefficient of expansion than has glass; ferro-nickel has a lower one. A combination of the two has practically the same.

**Macadamum.**—An aluminum-zinc alloy.

**Magnet Alloy.**—Steel alloys suitable for permanent magnets and other purposes are made by alloying with carbon steel, containing about 0.25 to 1.5 per cent. of carbon, about 5 to 19 per cent. of cobalt. Tungsten (or vanadium or molybdenum) or chromium, nickel and tungsten (or vanadium or molybdenum) may also be added, and also up to about 1 per cent. of manganese. The tungsten may vary up to about 10 per cent. and the nickel and chromium up to about 5 per cent. each. Cast ingots of the alloys may be heated to about 1000°C., forged, hardened at about 850 or 900°C., and magnetized. (Sir. R. A. HADFIELD, Br. Pat. 164,039, July 20, 1921.)

The alloy Fe<sub>3</sub>Co possesses remarkable magnetic properties, as the intensity of magnetization is from 10 to 20 per cent. higher than pure iron. See also "HEUSLER alloys."

**Manganese Bronze.**—Copper, 60; zinc, 40 with iron in small and manganese in varying quantities (S.A.E. Spec. No. 29). Should test about 60,000 lb. per sq. in. tensile strength; yield point about 30,000 lb. per sq. in.; elongation in 2 in., 20 per cent.

**Manganin** according to F. E. BASH, of Leeds & Northrup, should have a composition of copper, 82.17 per cent.; nickel 2.475 per cent.; manganese, 13.86 per cent.; iron 1.485 per cent. This alloy has a coefficient from 15–30°C. of  $+0.000003$  per deg. C.; from 15–45°C., of 0.0000038 per deg. C. The maximum resistance is at 25°C. The thermal e.m.f. against copper is  $5.6 \times 10^{-6}$  volts per deg. C. from 0 to 100°C.<sup>1</sup>

**Misch Metal.**—Cerium, 42 per cent.; lanthanum, didymium, etc., 57 per cent. (These figures are approximate only.) A cerium-free pyrophoric Misch metal has been produced by THOMPSON and KREMERS, containing Fe, La, and Nd.

**Mushet Steel.**—C, 2 per cent.; Mn, 1.75 per cent.; Si, 0.75 per cent.; Cr, 0.4 per cent.; W, 5.5 per cent.

**Nichrome.**—60 per cent. Ni, Cr 12, Fe 26, C 0.60, Si 0.40, Mn 1 per cent.

The electrical properties are: specific resistance, 109.6 microhms per cc. at 20°C.; 660 ohms per mil-foot at 20°C.; temperature coefficient, 0.000170 ohm per deg. C. per ohm at 20°C.; 0.000095 ohm per deg. F. per ohm at 20°C.

<sup>1</sup> F. E. BASH, *Bull. A.I.M.E.*, September, 1919, p. 1721.

## 668 METALLURGISTS AND CHEMISTS' HANDBOOK

The thermoelectric properties against nickel, as determined by Northrup, are:

Temperature, deg. C.	E.m.f. in microvolts
100 0 water.....	2,303
232.0 tin.....	5,970
419 0 zinc.....	10,535
629.0 antimony.....	15,065
1082.6 copper.....	30,796

The physical properties of cold-drawn nichrome are:

Specific gravity, 8.15.

Weight per cubic inch, 0.29 lb.

Ultimate tensile strength, 102,200 lb. per sq. in.

Specific heat, 0.111 per deg. C. over a range of 0° to 100°C.

Coefficient of linear expansion, 0.0000116 per deg. C. over a range of 20° to 100°C. (See p. 666.)

### ELECTRICAL RESISTIVITY OF NICKEL-IRON ALLOYS

Per cent. nickel	Electrical resistivity in microhm-cm	Mean coefficient of resistivity between 0 and $t^{\circ}\text{C}$ .
0	12.1	
0.27	13.1	
0.56	15.4	
1.07	16.9	
1.93	16.4	
7.05	26.9	
8.17	26.7	
10.20	28.6	
11.29	29.4	
12.07	30.3	
13.11*	34.8	
19.21	36.2	
22.0 + 3 Cr	....	$(784 - 0.13t) 10^{-6}$
22.11	38.7	
25.20	63.2	
26.2	....	$(844 + 0.01t) 10^{-6}$
26.40	65.5	
28.42	82.0	
28.7	....	$(700 - 0.20t) 10^{-6}$
30.4	....	$(897 - 0.43t) 10^{-6}$
35.0	....	$(1,561 - 1.69t) 10^{-6}$
35.09	81.1	
35.7	....	$(1,161 - 1.68t) 10^{-6}$
47.08	44.7	
75.06	22.1	
100.00	12.4	

\* Contains 0.89 per cent. C.

## MAGNETIC PROPERTIES OF NICKEL-IRON ALLOYS

Per cent. nickel	Density <i>D</i> in grams per cc.	Transformation temperatures centigrade (Curie points)		Saturation values at 0 deg. absolute; magnetic moment per unit mass ( <i>B-H</i> )		Curie constants (Weiss & Fox, 1911)
		Heat- ing, deg.	Cooling, deg.	$\sigma_0$	$4\pi\sigma_0 D$	
0	7.875	758	...	223.2	22,090	0.072
10	7.89	730	532	221.0	21,910	0.0577
20	8.02	625	218	210.8	21,340	0.0460
30	8.06	533	127	203.6	20,620	0.0315
40	7.63	365	...	184.2	17,660	0.0251
50	8.05	527	...	169.2	17,120	0.0227
60	8.29	599	...	146.8	15,290	0.0185
70	8.39	613	...	127.1	13,400	0.0157
80	8.52	562	..	103.1	11,040	0.0126
90	8.60	480	...	80.6	8,710	0.0100
100	8.86	374	...	58.8	6,550	0.0056

25 to 28 per cent  
nickel,  
0.3 to 0.5 per  
cent. carbon

30 to 35 per cent. 35 to 38 per cent.  
nickel nickel

Tensile strength	85,000 to 92,000	85,000 to 95,000	100,000 to 115,000
Yield point	35,000 to 50,000	40,000 to 50,000	64,000 to 78,000
Elongation in 2 in.	30 to 35 per cent.	30 to 40 per cent.	25 to 35 per cent.
Reduction of area	50 to 60 per cent.	40 to 60 per cent.	50 per cent.

Thermal conductivity 0.0326 calories per centimeter per second made with  $\frac{1}{4}$  in. diam. section; this value is one-fifth that of soft iron.

Nichrome will stand a maximum operating temperature of 1800°F. (982°C.) and makes an ideal material for ordinary heating elements.

The physical properties of cast nichrome are as follows:

Specific gravity....	8.15	Softening point...	2400°F.
Weight per cubic		Brinell hardness	
inch.....	0.29 lb.	number.....	165-175
Melting point.....	2660°F.	Specific heat...	0.111 at 100°C.

Coefficient of linear expansion 0.0000121 per deg. C. with a temperature range of 0°C. to 100°. Length of specimen under test 92.3 cm.

Thermal conductivity 0.0341 calories per centimeter per second; or in a ratio of 1 to 4.88 of soft iron, or expressed in

percentage 20.5 per cent. of the thermal conductivity of soft iron. Ultimate tensile, 50,000–55,000 lb. per sq. in.

**Nickel and Cobalt.**—The use of zirconium for hardening nickel or cobalt has been patented. Nickel with 8 to 10 per cent. of zirconium is claimed to take a fine cutting edge; either nickel or cobalt with 8 to 15 per cent. of zirconium has its melting-point reduced below that of any one of the three separate metals, with an increase of electrical resistance; and with 16 to 30 per cent. of zirconium the hardness is greatly increased, giving an alloy suitable for cutting tools. Some nickel-cobalt alloys resistant to acids are described just below, under non-corrosive alloys.

**Nirosta.**—A chrome-nickel steel developed at the Krupp works in Germany. Same as Enduro, p. 662.

**Nitalloy.**—A steel containing some aluminum, chromium and molybdenum, of which the surface has been treated with ammonia gas. Two typical analyses are: C 0.36; Mn 0.51; Si 0.27; Al 1.23; Cr 1.49; S 0.010; P 0.013; Mo 0.18; bal. Fe; and C 0.23; Mn 0.51; Si 0.20; Al 1.24; Cr 1.58; S 0.011; P 0.011; Mo 0.20; bal. Fe. The nitrided material will show a Brinell hardness of 900 to 1100.

**Non-corrosive Alloys.** It has been known for some time that cobalt-tin alloys containing about equal percentages (from 40 to 60) of the two metals are practically acid proof, withstanding even *aqua regia*, but the alloys are too brittle for practical use. According to ROBERT GRIMSHAW (*Chemical Engineer*, February, 1913) copper alloyed with from 5 to 20 per cent. of this Co-Sn alloy can be readily machined and still retains a high degree of non-corrodibility. The alloys are best prepared by dissolving the Co-Sn alloy in the copper. An alloy of Ni and Cu in equal proportions is highly resistant to hot, concentrated sulphuric acid. Even more resistant are the alloys prepared by adding copper to molten nickel-tungsten. The resistance normally increases with the percentage of tungsten, but specially resistant are: Ni, 78 per cent.; Cu, 20 per cent.; W, 2 per cent.; Ni, 70 per cent.; Cu, 25 per cent.; W, 5 per cent.; and Ni, 75 per cent.; Cu, 15 per cent.; and W, 10 per cent. These alloys are said to roll well. Electric resistance is high. Another still more resistant alloy is obtained by adding ferro-tungsten to cupronickel to give Ni, 52 per cent.; Cu, 40 per cent.; Fe, 4 per cent.; W, 4 per cent.

The silicon-iron alloys are resistant to both sulphuric and nitric acid. These alloys are marketed under the names tantiron, ironac and elianite in England, duriron, tantiron and corosiron in the United States. Duriron has approximately the following composition: Si, 14–14.5 per cent.; Mn, 0.25–0.35 per cent.; total carbon, 0.2–0.6 per cent.; P, 0.16–0.20 per cent.; S under 0.05 per cent. It melts at 2500–2550°F., has a specific gravity of about 7, a compression strength of about 70,000 lb. per sq. in., tensile strength about 12,000–14,000 lb., and a coefficient of expansion of about 0.00001565 per deg. F., conductivity about 2.5 per cent. that of standard annealed copper.



An approximate analysis of tantiron is as follows: Si, 14–15 per cent.; S, 0.05–0.15 per cent.; P, 0.05–0.10 per cent.; Mn, 2–2.5 per cent.; C (graphite), 0.75–1.25 per cent.; melts at about 2550°F.; sp. gr., 6.8; and tensile strength about 6–7 tons per sq. in.

**Palorium.**—A gold-platinum-group alloy, patented by the Palo Co. of New York. Melts at 1310°C. Superior to Pt in resisting fused alkalis; much inferior in resistance to HNO<sub>3</sub> and H<sub>2</sub>SO<sub>4</sub>.

**Permalloy.**—80 per cent. Ni, 20 per cent. Fe. Has an initial permeability 30 times that of soft iron. Developed by the Western Electric Co.

**Phonoelectric Wire.**—See silicon-bronze in table.

**Pyrophoric Alloys.**—These are in general cerium alloys. The commonest is ferro-cerium, containing about 15 per cent. Fe, 2 per cent. of Bi or Sb to harden it, 5 per cent. of copper to make it more fusible; and silicon, a general impurity of the rare earth metals, taken up from the clay crucibles in which the metal is melted. The most highly pyrophoric alloy is probably 1 part platinum with 3 parts of cerium. The most highly pyrophoric of the iron alloys is probably reached at about 70 per cent. of Ce. The alloy is hardest at 60 per cent. Ce. The alloys with 25 per cent. of magnesium or aluminum are brittle and easily pulverized. CeFe<sub>2</sub> is magnetic at ordinary temperatures, but becomes non-magnetic at 116°C. The presence of carbides is undesirable, as the alloys, unless kept under oil, oxidize and lose their efficiency. The raw materials for these alloys is the waste from the factories which extract thorium from monazite sand. The residues of the various rare earths are converted into chlorides and the anhydrous salts are electrolyzed in clay or in water-jacketed iron crucibles provided with iron cathodes. The fluorides are not convenient for reduction. (See "Misch Metal," p. 667.)

**Rezistal.**—A non-magnetic, flame and corrosion resistant alloy developed by the Crucible Steel Co. of America. It can be annealed to a Brinell hardness of 38 or less, but after oil quenching has a Brinell of 228, with corresponding yield points of 58,000 and 75,000 lb. per sq. in.

**Shakado.**—A Chinese "art bronze," really a cupro-gold alloy.

**Shibuichi.**—A Chinese "art bronze," really a cupro-silver alloy.

**Silanca.**—An English silver alloy, said to be resistant to tarnish, containing about 93 per cent. Ag; 4.5 per cent. Sb; and 2.5 per cent. Zn or Cd, or both.

**Silver Tarnish-resisting Alloys.**—Aluminum, beryllium, copper, germanium, magnesium, manganese, nickel and tellurium increase the liability of silver to tarnish. Antimony, cadmium, tin and zinc diminish the liability.

**Beryllium-copper Alloys.**—According to W. H. BASSETT, beryllium-copper alloys have high tensile strength with a comparatively high conductivity. Cu alloyed with 1.62 per cent. of Be gives a tensile of 145,000 lb. and a conductivity of 19.9 at 20°C.

**Stainless Steel.**—These originally were steels carrying 11 to 14 per cent. Cr and carbon of 0.3 or lower. The newer stainless steels are both high chromium and high nickel. See "Enduro," "Nirosta," "Rezistal."

**Stainless steel**—used chiefly for cutlery. A typical analysis is said to be: Fe, 86.6 per cent.; Cr, 12.7 per cent.; Co, 0.45 per cent.; C, 0.28 per cent.; Si, 0.01 per cent.; Mn, 0.12 per cent. Resists tarnishing in contact with food stuffs.

**Sykes Die Material.**—An iron-molybdenum alloy.

**Thermalloy.**—Fe, 75–85 per cent.; Cr, 10–20 per cent.; Si, 2–6 per cent.; 0.5–1 per cent. Mn and W, 0.2–2.0 per cent. C. M.p., 2760°F.; sp. gr., 7.60; coeff. of linear exp. per deg. F., 0.0000088; ultimate tensile strength, cast 60,000; forged 120,000 lb. per sq. in., elastic limit, cast, 50,000; forged, 75,000 lb. per sq. in.

**Toncan Iron.**—Contains copper and molybdenum.

**Tungsten-carbide Alloys.**—There are several alloys containing tungsten carbides, the pure carbides melting at 2600 to 2800°C. The alloys are:

	W, per cent.	C, per cent.	Co, per cent.	Fe, per cent.	Carbides, present
Diamonite.....	95 65	3 91	0	....	W <sub>2</sub> C
Elmarid .....	83 0	5 90	4.50	....	W <sub>2</sub> C
Thoran . . . . .	95 85	3 94	0	....	W <sub>2</sub> C, WC
Walramite .....	..	..	..	....	W <sub>2</sub> C, WC
Widia.....	87 50	5.68	6.10	....	WC

**Zilloy.**—A roofing material produced by the New Jersey Zinc Co. Apparently it contains (beside zinc) about 1 per cent. Cu and 0.01 per cent. Mg. The tensile strength runs about 35,000–60,000 lb. per sq. in. (Zn, 20,000–30,000) and the elastic limit about 13,500 (Zn, 5,200 lb. per sq. in.)

**Shell Steel.**—The general conditions for proper shell steel were laid down by DR. J. E. STEAD in a lecture given before the Cleveland Institute of Engineers (*The Engineer*, Jan. 14, 1916). These are: (1) There must not be such porosity of the base of the shell as to admit the hot propellant gas in on the exploding charge inside the shell. (2) The steel must not be too soft, for if it is, the shell bulges in the gun, causing excessive friction in the barrel. This may lead to the accentuated pressure from the propellant gases exceeding the bursting pressure. (3) The steel must not be too brittle. It should also break so that the fragments may have sharp points and edges, called by DOCTOR STEAD "shear-fractured surfaces." The analysis of many German shells shows that that country allows a very wide range for its shells, as follows:

Carbon.....	0.393 to 1.12	per cent.
Manganese.....	0.380 to 1.40	per cent.
Silicon.....	0.078 to 0.597	per cent.
Sulphur.....	0.027 to 0.083	per cent.
Phosphorus.....	0.028 to 0.105	per cent.

From the analyses of these German steels it appears that British makers have been insisting on a freedom from phosphorus that is totally unnecessary. From the analyses of German shell steel it is judged that basic bessemer steel is being used. This is argued from the nitrogen present, showing that open-hearth steel is not necessary.

The French chemical specifications for shell steel are said to be: Carbon minimum, 0.30 per cent.; Si, 0.15–0.25 per cent.; Mn, 0.50–0.80 per cent.; P, 0.03–0.08 per cent.; S, maximum, 0.05 per cent.

**Alloys Having Remarkable Properties at Very High or Very Low Temperatures.**—L. GUILLET. *Rev. metal.* 11, 1, 969–70 (1914).—Alloys or metals having a high temperature resistance have a breaking strength and an elastic limit of 5–8 kg. per sq. mm. at about 750–800°. A Ni-steel alloy hardened with Cr and W is described which has a breaking strength of 24 kg. at 800°. Another alloy shows a resistance of 50 kg. at  $-195^{\circ}$ , while soft steel gives a resistance of no more than 3 kg. at this temperature. TAMMANN cites two alloys of Cr-Co, one of which (Cr 25 per cent., Co 75 per cent.) has a resistance of 44.9 kg. at  $720^{\circ}$ ; the other (Cr 30 per cent., Co 70 per cent.) has a resistance of 65.1 kg. at the same temperature.

### Allotropy of Metals

In the preface to the first edition of this book I made mention that in its preparation I had often been puzzled by the fact that the various constants of the elements as determined by apparently equally reliable workers were hopelessly at variance. Some researches of PROFESSOR COHEN at the Van't Hoff Laboratory seem to give the answer to this seeming discrepancy.

To take a specific instance, dilatometric observations on the metal showed a sudden change at  $75^{\circ}\text{C}$ . The metal below  $75^{\circ}$  (the  $\alpha$  modification) has a specific gravity of 9.732, the metal above ( $\beta$  modification) 9.712. Although the transition point is well defined, quick cooling or quick heating permits the  $\alpha$  and  $\beta$  modifications to exist in the same mass.

Antimony also has strongly marked  $\alpha$  and  $\beta$  modifications, the transition point being about  $96^{\circ}\text{C}$ . The transformation temperature of copper is about  $70.5^{\circ}\text{C}$ .

The explanation, then, of the question of widely varying constants, is apparently that  $\alpha$  and  $\beta$  modifications exist in most of the metals and that accompanying a determination of the constants should be a statement of the relative proportion of  $\alpha$  and  $\beta$  modifications. As it appears to be true that at temperatures below the critical temperature the change from

$\beta$  to  $\alpha$  may be extremely slow, we might determine, say, the coefficient of linear expansion of bismuth each month for 6 months and get a different result each time, as what was originally a large amount of  $\beta$  modification changed slowly over to  $\alpha$ .

It does not appear, either, that it may not be found later that  $\gamma$  and even  $\delta$  modifications of some of the elements may not be found.

**Brittleness of Tin Foil.**—Some interesting investigations on aluminum containing tin have been carried out by E. HEYN and E. WETZEL of the Kaiser Wilhelm Institut für Metallforschung at Neubabelsberg and have been published in the *Proceedings* of this Institute, and summarized in *The Engineer* for Aug. 18, 1922. The investigations arose from the attempts to elucidate the origin of the brittleness of certain tin foil, which when freshly rolled was as soft and pliable as the average material, but which after a few days became through and through brittle. The origin has been traced to a small amount of aluminum contained in the tin. Even 0.25 per cent. of aluminum is sufficient to make the tin completely brittle in a short time, so that the foil breaks up on the slightest bending stress. The effect is probably due to great difference in electrolytic potential between tin and aluminum, which under moist atmospheric conditions results in the gradual conversion of the aluminum to aluminum oxide. The splitting process always commences at the surface and makes its way down into the center of the material. Tin which, owing to the above cause, has been rendered useless can be regenerated and completely freed from aluminum by melting, when the alumina remains as a gray residue. The addition of lead to the tin does not retard the advent of the brittleness but the addition of 2 or more per cent. of copper is advantageous.

**Die Casting of Zinc Alloys.**—H. E. BRAUER and W. M. PEIRCE recommend an alloy of 92 per cent. high-grade zinc; 3 per cent. Cu and 5 per cent. Al for die casting. This alloy has a tensile strength of 40,700 lb. per sq. in., a Brinell hardness of 54.7, and possesses high resistance to corrosion.

### Recrystallization of Metals<sup>1</sup>

When a metal is plastically deformed at a temperature so low that "strain hardening" results, it is said to be "cold-worked." Microscopic examination shows that the grains have been deformed in about the same manner and magnitude as was the piece of metal taken as a whole. Except in the soft metals like lead, tin, and zinc, these distorted grains do not change at room temperature. On heating, however, a temperature is reached, different for different metals and for various degrees of cold work, at which the distorted grain structure is replaced by new grains usually approximating an equiaxed shape. By "equiaxed grain" is meant one whose

<sup>1</sup>From an article by JEFFRIES and ARCHER, *Chem. and Met. Eng.*, Feb. 22, 1922.

diameter is approximately the same in all directions. Hardness tests show that most of the "strain-hardening" effect is lost with this change in structure. This change is usually referred to as "recrystallization," and the lowest temperature at which new grains visible under the microscope appear may be called the "recrystallization temperature."

## RECRYSTALLIZATION TEMPERATURE

Metal	Approximate lowest recrystallization temperature, deg. C.	Metal	Approximate lowest recrystallization temperature, deg. C.
Iron	450	Magnesium	150
Nickel	600	Tantalum	1000
Gold	200	Tungsten	1200
Silver	200	Molybdenum	900
Copper	200	Zinc	Room temp.
Aluminum	150	Lead	Below room temp.
Platinum	450	Tin	Below room temp.
		Cadmium	About room temp.

## Corrosion of Alloys by Sea Water

Ten-year corrosion tests of copper alloys in sea water were run by W. H. BASSETT and C. H. DAVIS (*Trans. A.I.M.E.*, 1925). In these tests copper suffered the greatest loss; low brass the least. The order of corrosion (the most corroded first) was: (1) Copper; (2) gilding (Cu 96.91, Zn 3.06, Pb 0.01, Fe 0.02); (3) muntz metal (Cu 60.49, Zn 39.29, Pb 0.15, Fe 0.07); (4) brass (Cu 61.79, Zn 38.06, Pb 0.13, Fe 0.02); (5) brass (Cu 63.32, Zn 36.50, Pb 0.15, Fe 0.03); (6) aluminum bronze (Cu 92.24, Al 7.76); (7) cupronickel (Cu 84.75, Ni 14.99, Fe 0.12, Mn 0.14); (8) cupronickel (Cu 75.46, Ni 24.12, Fe 0.15, Mn 0.27); (9) cupronickel (Cu 79.89, Ni 19.88, Fe 0.09, Mn 0.14); (10) bronze (Cu 94.72, Zn 0.22, Sn 5.00); (11) cupronickel (Cu 89.27, Ni 10.35, Fe 0.15, Mn 0.23); (12) phosphor bronze (Cu 95.72, Sn 4.09, P 0.29); (13) gilding (Cu 94.90, Zn 5.07, P 0.02, Fe 0.01); (14) bronze (Cu 92.73, Zn 6.54, Pb 0.02, Fe 0.06, Sn 0.65); (15) brass (Cu 72.45, Zn 27.47, Pb 0.06, Fe 0.02); (16) tobin bronze (Cu 61.31, Zn 37.72, Pb 0.06, Fe 0.04, Sn 0.87); (17) commercial bronze (Cu 89.93, Zn 10.02, Pb 0.02, Fe 0.01); (18) bronze (Cu 91.30, Zn 0.14, Sn 8.44); (19) leaded brass (Cu 67.29, Zn 31.99, Pb 0.69, Fe 0.03); (20) brass (Cu 66.11, Zn 33.83, Pb 0.04, Fe 0.02); (21) nickel silver (Cu 57.42, Zn 26.71, Ni 15.51, Fe 0.23, Mn 0.12); (22) brass (Cu 72.45, Zn 27.47, Pb 0.06, Fe 0.02); (23) admiralty (Cu 69.72, Zn 28.92, Pb 0.03, Fe 0.04, Sn 1.29); (24) low brass (Cu 80.84, Zn 18.08, Pb 0.07, Fe 0.06, Sn 0.95); (25) aluminum

bronze (Cu 95.14, Al 4.86); (26) low brass (Cu 80.07, Zn 19.86, Pb 0.05, Fe 0.02).

Practically the same order of failure under corrosion took place with condenser tubes. Pitting took place in the tubes of gilding, resulting in failure; dezincification takes place in the muntz metal, even under tinning. Monel metal was unsatisfactory.

Tests in acid mine waters (coal mines) showed extensive corrosion of all brasses. Bronzes showed much less corrosion than brasses. Cupronickel alloys corrode about like brasses. German silver corrodes extensively, and aluminum pits badly. Those materials showing marked resistance to corrosion were high-chromium steels, chrome-nickel steel, chrome-nickel iron, and high-silicon cast iron.

**Corrosion of Metals by Sea Water.**—J. NEWTON FRIEND exposed various ferrous and non-ferrous alloys for 4 years in the Bristol Channel. He thus summarizes the results (Institute of Metals, March, 1928, meeting). Nickel-copper (99.80 per cent. Cu, 1.75 Ni) lost 1.49 per cent. in tensile strength; screw metal (Cu 60.02 per cent.; Zn 38.61 per cent.; Pb 1.37; As < 0.05), 3.78 per cent.; copper, 4.37 per cent.; naval brass (Cu 62.03 per cent.; Zn 36.73 per cent.; Pb 0.23, Sn 1.01) 4.83; commercial zinc 10.31 per cent. In actual losses of weight the metals ranked as follows: Tin, ordinary English ingot, 0.04 per cent.; tin, Straits, 0.11; nickel, 0.44; lead (hard), 0.51; lead (soft), 0.65; screw metal, 1.44; stainless steel 2.44; muntz metal, 2.87; Armco iron, 3.02; nickel-copper, 3.03; arsenical copper, 3.41; copper, 3.65; commercial aluminum, 4.46; commercial zinc 4.70; nergandin brass, 5.04; wrought iron, 5.01 per cent.; naval brass, 5.58; mild steel, 5.60 per cent.

Because of the depth of fitting developed, however, FRIEND ranked the test pieces as follows: tin, nickel, hard lead, soft lead, screw metal, cupronickel, arsenical copper, copper, nergandin brass, naval brass, muntz metal (Cu 60.80, Zn 38.75, Pb 0.35, Sn 0.1); zinc, aluminum, Armco iron, wrought iron, mild steel, stainless steel. The ranking of copper above the brasses is extremely interesting as compared with BASSETT and DAVIS' 10-year tests given immediately above. The low corrodibility to tin and lead is also striking, though one would rather have expected this in view of the tin and lead objects dredged out of the Seine and the Thames in the museums of Paris and of London.

**Corrosion at Discontinuities of Metallic Protective Surfaces.**—ULICH R. EVANS (*Proc., Brit. Inst. Metals*, September, 1928) cites that in the breakdown of invisible protective films produced on metallic surfaces it is frequently found that corrosion at the breakdown point was frequently more intense than if no attempt had been made to protect the material. With films of paint and varnish, on the other hand, the phenomenon of rust-stiffing renders corrosion at cracks and pinholes less intense than if the film were everywhere absent. With metallic coatings cracks in the coating produced by

bending are more dangerous than uniformly distributed pores. If the coating metal is cathodic to steel (copper, nickel) the steel is corroded. If the coating metal is anodic to steel (zinc, cadmium) the coating suffers, the steel is protected. A zinc coating is rapidly attacked when partially immersed in a zinc-chloride solution, but alternate salt-spraying and drying builds up a protective film, a fact which explains the behavior of galvanized iron in practice. (NOTE.—Lead, tin, and aluminum are variably anodic and cathodic.)

**Protection of Aluminum and Its Alloys against Corrosion.—**

In a paper discussing this subject at the Derby meeting of the Inst. of Metals (Brit.), Sept. 6-9, 1927, H. SUTTON and A. J. SIDERY presented the following conclusions:

(1) The anodic treatment of aluminum, Duralumin, and certain aluminum alloys, followed by application of grease, affords a considerable measure of protection against corrosion by sea water.

(2) The increase in weight due to anodic treatment and the subsequent application of lanoline is negligible compared with that involved by plating.

(3) Parts in contact with iron, steel, copper, brass, or other copper alloys cannot be treated anodically, and treatment of the aluminum or aluminum alloy parts is necessary before attachment to extraneous metals or alloys.

(4) The "limiting radius of bending" of thin sheets of aluminum is increased slightly by the somewhat brittle anodic film.

(5) The insulating properties of the film are likely to cause difficulty in securing good electrical contact where desired.

(6) The "throwing-power" of the anodic process is probably much greater than that of the best-known plating bath, and enables parts having irregular shape to be treated without special arrangements.

The experiments on the zinc- or cadmium-plating processes permit the following observations:

(a) Zinc and cadmium may be deposited on aluminum and all the aluminum alloys so far investigated, and deposits 0.0005 in. thick afford a considerable measure of protection, with the single exception of cadmium on aluminum.

(b) Deposits of this thickness weigh approximately 0.6 lb 0.74 oz./ft.<sup>2</sup>.

(c) Parts in contact with steel and other metals may be plated without dismantling.

(d) The "throwing-power" of zinc and cadmium cyanide baths is good, but not so good as that of the anodic oxidation process. That of the zinc sulphate baths tried appears to be relatively poor.

**Protection by Anodic Oxidation.**<sup>1</sup>—A process for the protection of aluminum and certain aluminum alloys by anodic oxidation is due to G. D. BENGOUGH and J. M. STUART.<sup>2</sup>

<sup>1</sup> *Trans. Brit. Inst. Metals*, 1928.

<sup>2</sup> G. D. BENGOUGH and J. M. STUART, English Patent 223,994, Aug. 2, 1923.

The process consists in making the articles of aluminum or alloy the anode in a 3 per cent. aqueous solution of chromic acid or its equivalent salt in water, maintained at a temperature of 40°C. The voltage is raised from 0 to 50 volts over a period of 1 hr., during which a dense resistant coating of oxide forms on the surface of the articles. Subsequent application of grease or paint improves the protection against corrosion afforded by the film. The ungreased film may be dyed by immersion in aqueous solutions of dyes for which aluminum hydroxide is a suitable mordant.<sup>1</sup>

Early work on this process was described in a recent paper to the British Association,<sup>2</sup> and the operation of the process is here described briefly.

The surface of the aluminum or alloy is first cleaned to remove adhering impurities, grease, etc. For this purpose washing with petrol or benzol, followed by dipping in hot water, has proved satisfactory. The article is then immersed in boiling water for a few minutes and transferred to the anodic bath, in which it is connected to the positive lead by means of aluminum or Duralumin wire, strip, or rod to which it is firmly attached. Unless good contact is obtained initially and maintained by suitable pressure, the work is liable to become insulated from the conductor by the film produced during treatment.

Pieces may be treated, on the other hand, by double immersion, each immersion covering rather more than half of the surface of the piece so that no part remains untreated. This procedure necessitates penetration of the film, e.g. by spring steel clips having sharp points, in order to permit the treatment of the second portion. It also results in the formation of a band of different color from that of the rest of the piece, but this has been found not to be a detrimental effect.

The cathodes used are of graphite, and it has been found advantageous to have a front area of graphite electrodes equal to or greater than that of the work under treatment.

The following conditions have been adopted as standard:

The electrolyte consists of 3 per cent. solution of chromic acid crystals in water, maintained at 40°C. and agitated moderately.

\*The voltage of the bath is increased gradually from 0 to 40 volts in 15 min. and is maintained at 40 volts for 35 min. It is then raised to 50 volts in the course of 5 min., and held at this value for 5 min. The object is then washed in water and dried. Mild steel tanks have been used exclusively as containers for the electrolyte.

The current has a heating effect which becomes appreciable in a bath in which considerable areas are under treatment, and

<sup>1</sup> G. D. BENGGOUGH and J. M. STUART, English Patent 223,995, Aug. 2, 1923.

<sup>2</sup> G. D. BENGGOUGH and H. SUTTON, British Association, Aug. 9, 1926, *Engineering*, 1926, Vol. 122, pp. 274-277. See also G. D. BENGGOUGH and J. M. STUART, "The Anodic Oxidation of Aluminium and its Alloys as a Protection against Corrosion," (*Report of the Department of Scientific and Industrial Research*), H. M. Stationery Office, 1926.



cooling is necessary in order to maintain a steady temperature. Variations of  $\pm 2^{\circ}\text{C}$ . are permissible.

Articles for treatment should consist entirely of aluminum, or aluminum alloy suitable for treatment. Contact with iron, steel, brass, or other metal prevents the normal operation of the process, as the main effect of the current is then concentrated upon the foreign metal. In the case of brass and copper severe corrosion occurs, with contamination of the electrolyte.

During the treatment the anodic film constitutes the principal resistance in the circuit. The heating effect of the current causes a layer of electrolyte in contact with the film to become heated and to rise in a convection current to the surface of the bath if agitation be insufficient.

If in anodic oxidation of aluminum or aluminum alloy the voltage be raised continuously, a point is reached at which the anode film breaks down. At this point there is a marked increase in current for each subsequent small increase in voltage. This point, or "breakdown voltage," is accompanied by pitting of the aluminum or alloy, with formation of a porous, non-protective coating. The voltage at which "breakdown" occurs decreases with increasing temperature of the electrolyte. It is therefore important to avoid accumulation of overheated electrolyte as far as possible.

Some oxygen gas is liberated at the anode under treatment, and it is necessary to avoid this gas being trapped in parts of irregular shape.

As would be expected from the nature of the process, the "throwing-power" is excellent, and deep recesses receive a coating indistinguishable from the normal. Only in the case of long tubes of small bore and similar cases is there any marked variation in film thickness, and in such cases the resistance of the electrolyte is the controlling factor. Pores and defects in castings, and also in rolled and forged aluminum and light alloys, appear to receive the coating. Pores and defects retain some chromic acid even after prolonged washing, and while this effect produces unsightly stains, it has been found not to be injurious. On the other hand, it serves to show up defects which would otherwise escape detection.

The treatment of commercial aluminum sheet requires a current density of 2.8 to 3.6 amps./ft.<sup>2</sup> as a maximum. With aluminum and also with aluminum alloys the current consumption varies with the nature of the surface of the metal, being high for rough surfaces and low for smooth surfaces. It also varies with the temperature of the electrolyte, and to a slight extent with the working age of the electrolyte.

**Corrosion Resistance—Cu-Al Bronze.**—Of the less expensive alloys, the corrosion resistance of copper-aluminum-iron bronze fits it very well for use with certain acids.

## 680 METALLURGISTS AND CHEMISTS' HANDBOOK

	Bronze A	Bronze B
Cu.....	87.0	85.60
Al.....	9.8	10.81
Iron-alloy.....	3.14	3.57
	99.94	99.98
Ultimate tensile per sq. in..	74,800 lb.	66,600 lb.
Reduction in area.....	19.0 %	13.0 %
Elongation in 2 in. ....	21.0 %	11.5 %
Sp. gr.....	7.71%	7.58%
Sulphuric acid, dil.....	Resistant	Resistant
Sulphuric acid, conc.....	Resistant	Resistant
Hydrochloric.....	Non-resistant	Non-resistant
Ammonia.....	Non-resistant	Resistant
Sodium hydroxide.....	Resistant	Resistant
Lactic acid.....	Resistant	
Phosphoric acid.....	Resistant	
Tartaric acid.....	Resistant	
Acetic acid.....	Resistant	Non-resistant

### CRITICAL DENSITY RATIOS OF METALS AND THEIR OXIDES

Metal	Ratio	Metal	Ratio
Aluminum.....	1.28	Manganese.....	2.07
Barium.....	0.78	Nickel.....	1.68
Cadmium.....	1.32	Potassium.....	0.51
Caesium.....	0.42	Silicon.....	2.04
Calcium.....	0.78	Sodium.....	0.32
Chromium.....	3.92	Strontium.....	0.69
Cobalt.....	2.10	Thorium.....	1.36
Copper.....	1.70	Tin.....	1.33
Iron.....	2.06	Tungsten.....	3.30
Lead.....	1.31	Zinc.....	1.59
Lithium.....	0.60	Zirconium.....	1.55
Magnesium.....	0.84		

If this above ratio exceeds unity, oxidation (rusting) forms a protective coating. If less than unity, there is no protection to the metal (N. B. PILLING and R. E. BEDWORTH, *Chem. and Met. Eng.*, July 12, 1922).

**Chemical Lead.**—According to W. HENRY IBBOTSON, *Industrial Chemist*, July, 1929, pp. 267–268, the first essential is purity, because the acid-resisting properties are greatly reduced by even small quantities of impurities. A very small quantity

of copper, however, probably is beneficial, at least for most uses involving exposure to acid. It may be that the copper counteracts the harmful effect of traces of other metals, rather than having a positive beneficial effect of its own. The British Engineering Standards Association specifies upper limits as follows: silver, 0.002; bismuth, 0.005; iron, 0.003; antimony, 0.002; zinc, 0.002, and copper, 0.05 per cent., the total impurities other than copper not to exceed 0.01 per cent. Since the protective effect of lead depends on formation of a corroded film on the surface which prevents further attack, use should be under conditions not subject to mechanical disturbances which might remove or destroy the continuity of this film. For this reason, also, the thickness of lead to be used should be adapted to the severity of the conditions. For some uses, antimonial lead is preferable to the pure metal—e.g., in acid eggs and vessels which need sufficient rigidity for self-support and will be exposed only to cold acid.

### Fluxes for Soldering and Welding<sup>1</sup>

Iron or steel.	Borax or sal-ammoniac, zinc chloride.
Tinned Iron.	Resin or tin chloride.
Copper and brass.	Sal-ammoniac or zinc chloride.
Zinc.	Ammonium phosphate, zinc chloride
Lead.	Tallow or resin.
Lead and tin pipes.	Resin and sweet oil.
Aluminum.	Borax 96 parts, sodium bisulphate 4 parts. <sup>1</sup> Cryolite is about the best for arc welding.

<sup>1</sup> Given as a Danish flux by *Brass World*, May, 1915. Seems very questionable whether it will work.

**Soldering Aluminum.**<sup>2</sup>—All metals or alloys used for soldering aluminum are electropositive to it. A soldered joint therefore is attacked and disintegrated when exposed to moist air. Joints should therefore never be made by soldering unless they are protected by paint or varnish, or are in heavy castings. Solders are best applied without a flux or by using paraffin as a flux, after preliminary cleaning and tinning of the surface.

### SUGGESTED COMPOSITIONS

Zn 15 — 50; Sn balance  
Zn 8 — 15; Al 5 — 12; Sn balance

<sup>1</sup> MEGRAW, "Practical Data for the Cyanide Plant."

<sup>2</sup> *Bureau of Standards Circ 73* (1923)

## IMPURITIES IN COMMERCIAL METALS

**Aluminum:** Fe, 0.18 per cent.; Si, 0.17; Na, 0.05; Cu, tr. Electrolytic aluminum will carry 98.52 to 99.34 per cent. Al, and Si from 0.07 to 1.14 per cent. according to RICHARDS

ANALYSES OF ALUMINUM  
(By W. H. WITHEY, Nat. Phys. Lab.)

	A	B	C	D
Copper...	0.0265	0.0800	0.0463	trace
Iron.....	0.1829	0.4077	0.1972	0.1522
Zinc.....	0.0060	0.0120	0.0075	0.0024
Silicon....	trace	0.2320	trace	trace
Silica.....	0.333	0.340	0.290	0.459
Nitrogen...	0.040	0.006	0.042	0.092
Sodium....	trace	trace	trace	trace
Sulphur.....	nil	nil	nil	nil
Phosphorus...	nil	nil	nil	nil

CHEMICAL ANALYSES OF REFINED COPPER<sup>1</sup>

Element	Lake wire bar	Lake arsenical ingot	Electro- lytic wire bar	Best selected English
Cu + Ag	99.900	99.4385	99.9548	99.5510
Cu	99.890	99.4131	99.953	99.530
Ag	0.0096	0.0254	0.0018	0.021
	(2.8 oz.)	(7.41 oz.)	(0.56 oz.)	(7.02 oz.)
Pb	2.0031	0.0027	0.0010	0.1331
Bi	0.0000	0.0000	0.0000	0.0000
As	0.0062	0.3183	0.0000	0.0071
Sb	0.0000	0.0000	0.0009	0.0087
Se + Te	0.0020	N d	0.0026	0.0086
Fe	0.0028	0.0056	0.0038	0.0044
Ni	0.0090	0.0153	0.0028	0.1112
Zu	0.0000	0.0000	0.0000	0.0000
S	0.0016	0.0071	0.0026	0.0074
O (by diff.)	0.0753	0.2143	0.0315	0.1705
Sn				
Conductivity, annealed....	96.49		100.45	
Conductivity, hard drawn.....	93.84		97.61	
Difference due to hard drawing..	2.65		2.81	
Tensile strength, lb. per sq. in..	67.590		66.300	
Twists in 6 in. ....	17		34.0	
Elongation, per cent. . .	1.03 <sup>2</sup>		1.04 <sup>3</sup>	
Bends, annealed.....	11.0		14.0	
Diameter of wire, in.....	0.080		0.080	

<sup>1</sup> HOFMAN, "Metallurgy of Copper," p. 12.

<sup>2</sup> In 8 in.

<sup>3</sup> In 60 in.

**Antimony:**<sup>1</sup> **COOKSON'S:** Pb, 0.041; Sn, 0.035; As, tr.; Cu, 0.04; Fe, 0.010; Zn, tr. **COOKSON'S:** Pb, 0.102, Zn, tr.; As, 0.092; Bi, none; Cu, 0.046; Cd, none; Fe, 0.004; Zn, 0.034; Ni and Co, 0.028; S, 0.086; Sb (by difference), 99.608. **HALLETT'S:** Pb, 0.669; Sn, 0.175; As, tr.; Cu, 0.038; Fe, 0.014; Zn, tr. **HALLETT'S:** Pb, 0.718; Sn, 0.012; As, 0.021; Bi, none; Cu, 0.046; Cd, none; Fe, 0.007; Zn, 0.023; Ni and Co, none; S, 0.128; Sb (by difference), 98.856. **Japanese:** Pb, 0.443; Sn, 0.175; As, 0.008; Cu, 0.034; Fe, 0.015; Zn, tr. **Japanese:** Pb, 0.424; Sn, 0.012; As, 0.095; Bi, none; Cu, 0.043; Cd, none; Fe, 0.007; Zn, 0.023; Ni and Co, none; S, 0.201; Sb, 99.195. **Chinese:** Pb, 0.018, Sn, 0.035; As, 0.017, Cu, 0.008; Fe, 0.007; Zn, tr. **Chinese:** Pb, 0.029; Sn, none; As, 0.090; Cd, none; Fe, 0.004; Zn, 0.027; Ni and Co, tr.; S, 0.078; Sb, 99.760.

**Bismuth (American):** Pb, Au, Cu, Sb, Te, traces; Ag, 1.37 oz. per ton; Fe, 0.009 per cent.

**Copper (electrolytic):** Cu, 99.89; Bi, none; Ni, 0.0100; As, 0.00108; Sb, 0.00515 per cent.; Ag, 0.96 oz. per ton. The presence of a small amount of oxygen, less than 0.06 per cent., seems to affect the copper beneficially, and in most of the electrolytic copper, which carries from 99.89 to 99.94 per cent. Cu, oxygen forms by far the largest part of the balance.<sup>2</sup>

**Iron, pure,** is defined by the American Society for Testing Materials (Atlantic City meeting, 1915) as containing under 0.02 per cent. C; 0.03 per cent. Mn; 0.03 per cent. S; 0.01 per cent. P; 0.03 per cent. Cu.

**Lead (electrolytic):** Ag, 0.29 oz. per ton; Bi, 0.0024 per cent.; Cu, 0.0010; As, tr.; Sb, 0.0066; Fe, 0.0028.

**Lead (PARKES process), American:** Bi, 0.066–0.110; Sb, 0.0028–0.0076; As, 0.00025–0.009 per cent.<sup>3</sup>

**Nickel:** Mond process, Ni, 99.72; S tr; Fe 0.06; Co 0.09; Si tr, Cu none. **Int. Nickel Cos.** best electrolytic, Ni, 99.7; Fe 0.01; Co, 0.02; Cu none. Tensile about 72,000 lb. per sq. in. Brinell about 150.

**Tin.**—(Pulo Brani, 1892, after HENRY LOUIS): Sn, 99.76; Sb, 0.07; Pb, 0.02; Fe, 0.14 per cent.; Cu, As, none. **English:** Sn, 99.73; Fe, 0.13; Pb, tr.; Cu, tr. The presence of over 0.8 per cent. of copper spoils tin for tin-pot work, according to my own experience, yet LOUIS gives as a typical English tin analysis: Sn, 98.64; Fe, tr; Pb, 0.20; Cu, 1.16 per cent.

<sup>1</sup> *Min. and Sci. Press*, July 10, 1915.

<sup>2</sup> See also pp. 682 and 780.

<sup>3</sup> See also p. 737.

## SHEET-ZINC GAGE

Gage number	American		Belgian		Vieille Montagne	
	Thickness, decimals of an inch	Weight per sq. ft., lb.	Thickness, decimals of an inch	Weight per sq. ft., lb.	Thickness, decimals of an inch	Weight per sq. ft., lb.
1	0.002	0.075	0.0018	0.068	0.004	0.150
2	0.004	0.150	0.0036	0.135	0.006	0.225
3	0.006	0.225	0.0055	0.206	0.007	0.263
4	0.008	0.300	0.0073	0.274	0.008	0.300
5	0.010	0.375	0.0091	0.341	0.010	0.375
6	0.012	0.450	0.0110	0.413	0.011	0.413
7	0.014	0.525	0.0128	0.480	0.013	0.488
8	0.016	0.600	0.0146	0.548	0.015	0.563
9	0.018	0.675	0.0165	0.619	0.018	0.675
10	0.020	0.750	0.0180	0.675	0.020	0.750
11	0.024	0.900	0.0217	0.814	0.023	0.863
12	0.028	1.050	0.0254	0.953	0.026	0.975
13	0.032	1.200	0.0290	1.088	0.029	1.088
14	0.036	1.350	0.0326	1.223	0.032	1.200
15	0.040	1.500	0.0364	1.365	0.036	1.425
16	0.045	1.688	0.0400	1.500	0.043	1.613
17	0.050	1.875	0.0437	1.639	0.048	1.800
18	0.055	2.063	0.0478	1.793	0.053	1.988
19	0.060	2.250	0.0509	1.909	0.058	2.175
20	0.070	2.625	0.0581	2.179	0.063	2.363
21	0.080	3.000	0.0728	2.730	0.070	2.625
22	0.090	3.375	0.0764	2.865	0.077	2.888
23	0.100	3.750	0.0800	3.000	0.084	3.150
24	0.125	4.688	0.0896	3.360	0.091	3.413
25	0.250	9.375	0.0992	3.720	0.098	3.675
26	0.375	14.063	0.1088	4.080	0.105	3.938
27	0.500	18.750	.....	.....	.....	.....
28	1.000	37.500	.....	.....	.....	.....

See p. 655 for sheet-metals other than zinc.

**Zinc.**—The impurities found in zinc may amount to 2 per cent. of its weight. They are: Pb, Fe, Cd, Cu, C, Si, As, Sb, S, Sn, Ag, Tl, In and Ga. Tin has been found in New Jersey metal. A moderate tenor in Pb makes zinc ductile and malleable, but over 1.5 per cent. Pb renders it tender. Zinc for the brass trade should not carry over 0.05 per cent. Fe. Cd is objectionable if the zinc is to be used for zinc white. Copper and tin both render the zinc hard and brittle. Arsenic renders spelter brittle and hard to melt. It is also objectionable in zinc which is to be used for generating hydrogen or in cyanide precipitation, owing to the danger of poisoning workmen with arseniuretted hydrogen.

## Roasting

## DETAILS OF MONTANA ROASTING-FURNACES

	Tons roasted in 24 hr.	Horsepower required	% sulphur in concentrates	% sulphur in calcines	Area of hearths, sq. ft.	Concentrates per sq. ft. of hearth, lb.	Lb. of coal per ton of con- centrates	Cost of roasting per ton
Hand reverberatory, 69½ ft. × 16 ft. ....	13	.....	35	7-8	1112	12	307.0	\$2.00
Allen-O'Hara, two hearths, 94 ft. 0 × 9 ft	51	3 64	35	8	1692	77	145.0	0.78
Brückner cylinder, 8 ft. × 16 ft. ....	18- 20	1.5	37	9.5	...	...	540.0 <sup>1</sup>	1 25
Pearce, single deck. ....	14 <sup>1</sup>	1 5	32	7-8	505	55	400 0	0.98 <sup>2</sup>
Pearce, double deck, 6-ft. hearths. ....	30 <sup>1</sup>	3 0	35	6-7	1010	59	400.0	0.98 <sup>2</sup>
Pearce, double deck, 7-ft. hearths. ....	42 <sup>1</sup>	3.0	35	6-7	1218	69	182.0	0.98 <sup>2</sup>
Keller-Galord-Cole, two sets of six hearths. ....	50	1½	38	7-10	2592	38	67.0	.....
Wetthey, two sets of four hearths, 50 ft. × 5 ft..	60	4.0	40	8	2000	60	110.0	.....
Wetthey, two sets of four hearths, 65 ft. × 10 ft.	90	4 0	35	5-6	2600	70	80.0	.. . .
Herreshoff, five hearths. .	5-6		35	6	135	80	....	0.40
MacDougall-Evans- Klepetko, six hearths .	40	1.667	35	7	652	84	...	0.35
Pearce multiple, six hearths. ....	56 <sup>1</sup>	12	35	6-7	2947	38	28.5	0.98 <sup>2</sup>

<sup>1</sup> Data obtained from operations of six months at Great Falls.<sup>2</sup> Average<sup>3</sup> These low figures are due to the character of the ore (Gagnon Mine) which carries from 8 to 12 per cent. of zinc. The table is by HOFMAN.HANDLING OF FINE ORES AND CONCENTRATES  
IN SALT LAKE VALLEY LEAD SMELTERSBy L. D. ANDERSON<sup>1</sup>

Changes in milling surface, particularly the development of flotation, have introduced a new set of problems in sintering. Although it is felt that these problems have not yet been solved in an entirely satisfactory manner this abstract records the 1929 practice of the Salt Lake Valley smelters.

<sup>1</sup> New York meeting, February, 1929, A.I.M.E.

Most of the sulphides smelted today are flotation concentrates, sometimes over 70 per cent. in lead. They are extremely fine, many mills grinding the ore so that from 60 to 80 per cent. will pass through screens of 200 mesh. The physical condition is often disconcerting to the smelter metallurgists. Some are of about the consistency of putty. Others are of a sticky, slimy nature. Others again, dried to the limit, are powders. Since the down-draft sintering charge must be porous enough to let air be drawn through it reasonably well, must be thoroughly mixed, and must have some coarse material in it to segregate out and form a layer on the grates, it will be understood that this extremely fine material has made necessary still further elaboration in the equipment and processes of preparing sulphides for the blast furnaces. The high metal contents of the concentrates also caused incipient fusion of the lead which fritted the material, closed off the passage of air and ended the roasting operation before the necessary amount of sulphur had been removed. In addition the resultant sinter was weak and friable so that the blast furnaces which had been running freely with the old hard sinter from crude sulphides were choked.

**Double Roast.**—Probably the biggest step in the solution of the above problem came in the development of the "double roast," wherein after a first rough sintering the entire mass resulting is crushed and sintered again, usually with an admixture of a small percentage of new material, both sulphide and oxide. It probably developed from the practice of screening the sinter and returning the fines to the charge for resintering. As the sinter from fine concentrates began to get weaker and weaker the proportion of these fines became greater and greater until finally some one hit upon the idea of returning the entire first sinter for a second sintering, adding just enough new sulphides to bring the sulphur content up to a point where it would ignite again. It was found that the "pop-corn" particles from the first roast were effective in opening the charge for the passage of air. The second sintering also brought the sulphur down in the final product to about half of what it was in the first sinter. The lumps of sticky concentrate which did not sinter the first time over were at least dried so that they mixed better with the second charge.

As observed in the Salt Lake Valley this second or double sinter is a decidedly better product than that which was obtained when fine concentrates were first sintered. It is still rather weak as compared to that made from crude sulphides. Two materials have from time to time been added to the charges to strengthen the sinter, namely crushed or granulated slag, and matte. Although these materials undeniably do strengthen the sinter, their use is not always an ultimate economy.

**Reduction of Double Sinter.**—Reduction of the double sinter in the blast furnace seems a little more difficult as fairly high percentages of coke are used together with considerable scrap iron. The three smelters are using on the average about 13



per cent. of a by-product coke running 85 to 87.5 per cent. fixed carbon. At times the amount used is as low as 12 per cent., or less, and occasionally up to 14 per cent. or more. The amount of scrap iron used on the charge has considerable influence on the amount of coke found necessary for good reduction.

High blast pressures prevail generally. In fact, the plants use pressures which are reported as reaching at times heights twice as great as those considered safe a few years ago. Tooele has been using a blast pressure of 44 oz. per sq. in. and Midvale about 48 to 52 oz., measured at the blowers. Murray operates on the principle of a fixed amount of air per minute letting the blast pressure go where it will, within bounds. This is somewhat the practice at Midvale although there the maximum is limited to 52 oz. At Murray, it is stated, it has gone to 60 and 70 oz., and even more, momentarily. This is quite an innovation when compared to the old practice of keeping the pressure fairly uniform, regulating the quantity to so maintain it. Ten years ago the blast pressures were more commonly in the neighborhood of 36 to 42 oz.

Piston blowers are used to obtain these pressures, cycloidal blowers having too great a slip. With a charge composed mainly of sinter, and that weak and friable though porous, the blast-furnace charge column now has a multitude of small passages for the blast instead of the comparatively smaller number of larger passages existing in the days of strong sinter in large cakes. While the actual amount of air per ton of charge is probably no greater, if not less, than in former days nevertheless the resistance is very much greater, hence the higher pressures.

These higher blast pressures although difficult to handle, together with the higher percentages of lead on the charges, have naturally resulted in fast running and new records in tonnages per square foot of hearth area. Without taking into account the so-called "concentration" charges for resmelting matte, which always ran extremely fast, the present rate of smelting puts through 5 to 6 tons of charge exclusive of coke, per square foot of hearth area per 24 hr. Five tons is about the general average, day in day out, without allowance for lost time. Naturally at times when the furnaces have become well "crusted up" and approach the ends of their campaigns, the rate is not so good. On the whole, however, there has been a gain in speed. This, plus the higher percentage of lead on the charges, has in turn brought about a rapid running of bullion from the lead wells. The furnaces need close watching for if they do start channeling or blowing through the effect is rather startling. Nevertheless, they run surprisingly quietly with the high blasts.

**Roasting Equipment.**—At the Tooele smelter of the International Smelting Co. all lead plant roasting is at present done on 10 Dwight-Lloyd machines, four of which are used for the first or rough roast sinter and six for the finished sinter. The proportioning of the charges is effected in the conventional

manner by individual feeders from the respective bins, all discharging onto one common belt conveyor. Most of these feeders are of the revolving disk, or modified Challenge type. For sticky concentrates, however, rubber belt feeders have been installed under separate auxiliary hoppers. Concentrates drop into these hoppers from the overhead bins. By this means an opening is left between the hoppers and the bins through which a pokebar can be manipulated to bring down the concentrates when they hang up in the bins above. In addition to this pokebar is a piece of pipe attached at one end, through a valve, to a length of air hose, making it possible to use compressed air to further assist in dislodging hung-up material. This whole arrangement is quite helpful. The first conveyor collecting material from the feeders discharges into a larger mixer. This is like a very flat inverted frustum of a cone. Four arms driven by bevel gears and having plows mounted in them turn the charges over and work them into the central discharge hole through which they drop on to the conveyor belt leading up into the sintering building proper. A third conveyor belt distributes the charges into the respective machine hoppers by means of a traveling tripper. From these hoppers the material is fed onto the machines by adjustable revolving disk feeders. A reciprocating swinging chute distributes the charge uniformly across the width of the sintering machine pallets. The same device is used at the Midvale plant of the United States Smelting, Refining & Mining Co.

For ignition all three of the valley smelters use a furnace fired with coke breeze and supplied with a gentle blast of air. The uptake of this furnace makes a complete 180 deg. turn, discharging the gases of combustion downward on the moving bed of charge on the sintering machine. This furnace has proved to be a great help in getting a good ignition of the charges being in fact much better than the oil-fired muffles originally used.

The entire first sinter, fines and all, is taken to the sulphide mill in railroad cars and crushed down to  $\frac{1}{4}$  to  $\frac{3}{8}$  in. size. After this crushing it forms about 70 per cent. of the second or finishing sinter, the remaining constituents of which are about 10 per cent. siliceous diluent, 10 per cent. crude sulphides and 10 per cent. miscellaneous. On discharging from the machines the sinter drops over a grizzly with  $\frac{3}{8}$ -in. openings into railroad cars for transport to the blast-furnace charge bins. The return fines through the grizzlies go back to the first or rough sinter where they are of benefit in opening up a charge which would be pretty dense otherwise, composed as it is of floatation concentrates, both oxide and sulphides, dust from the Cottrell precipitator, fine diluent, and such like. The first sinter charges run about  $12\frac{1}{2}$  to 13 per cent. sulphur and are roasted down to about 6 per cent., while the finishing charges run about  $9\frac{1}{2}$  per cent. sulphur and are roasted to as low as 1.7 per cent. The importance of getting the finished roast as low as possible in sulphur so as to keep the matte fall from the blast furnaces low is self-evident.

At Murray, multiple-hearth roasters of the Wedge type are used to preroast high-sulphur concentrates, such as pyrite, before submitting them to the sintering treatment. These iron concentrates are particularly troublesome to sinter, making weak cakes unless mixed in the proper proportions with other material of better sintering qualities. Dusting was particularly troublesome on these roasters until the adoption of a mechanism for moistening the calcines as they were discharged.

One detail of practice at Murray which has been helpful in the handling of the troublesome flotation product is the manner in which it is bedded with crushed crude sulphides in the unloading bins before transport to the charge bins of the sintering plant proper. By this means the drier and coarser crushed crude sulphides add their characteristics to the wetter and finer flotation concentrates resulting in a mixture which can be carried on the conveyor belts to the charge bins and out on the feeder belts without too much trouble.

### Fuel Used in Firing the Dwight-Lloyd Sintering Charge

The use of oil for starting the roast in the Dwight-Lloyd palates is attended with excellent results. E. H. HAMILTON used .50 to .78 gal. of oil per ton of sinter produced, the larger amount being used when the charge contained a large excess of highly oxidized iron fines (*Min. and Met.*, November, 1925).

When oil is cheap no better starting fuel can be used, but it must be cheap to compare with powdered coal. With oil at 7.5 cts. per gal., using .73 gal. per ton of sinter produced the cost of fuel for the starting torch is 5.5 cts. per ton of sinter produced.

With coal at \$3.75 per ton, plus \$1.00 for pulverizing, using 7.6 lb. of coal per ton of sinter, the cost is about 1.9 cts. per ton of sinter produced.

Oil of 28 to 32° Bé., or 7.4 lb. per gal., gives about 19,580 B.t.u.'s per lb.

Powdered coal at \$5 per ton gave 14,000 B.t.u.'s per lb. and coke at \$12 per ton gave 12,784 B.t.u.'s per lb.

At 7.5 cts. per gal., 1 ct. spent for oil will supply 19,450 B.t.u.'s.

At 10 cts. per gal., 1 ct. spent for oil will supply 14,500 B.t.u.'s.

At \$5 per ton, 1 ct. spent for coal will supply 56,000 B.t.u.'s.

At \$12 per ton, 1 ct. spent for coke will supply 21,000 B.t.u.'s.

Thus powdered coal gives two and a half times as much heat per unit cost as coke or even oil at 7.5 cts. per gal.

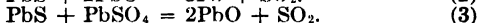
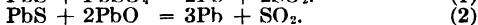
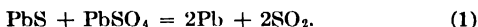
If we assume that 600 tons of sinter are made per day the fuel cost will be:

Oil @ 7.5 cts. per gal. . . . .	\$33.00 per day or \$12,945 per year
Oil @ 10 cts. per gal. . . . .	\$44.00 per day or \$16,060 per year
Coal @ \$5 per ton . . . . .	\$11.40 per day or \$ 4,161 per year

Powdered coal possesses an advantage in that any particles of coal not immediately and completely burned are filtered out and remain in the upper surface of the cake until consumed.

**Formation of Zinc Ferrite in Roasting.**—In roasting marmatites it may be assumed that all of the iron will be united with zinc to form  $\text{ZnO} \cdot \text{Fe}_2\text{O}_3$ . Therefore each unit of iron will render 0.584 units of zinc insoluble. In roasting ores where the iron is present as pyrite to pyrrhotite each unit of iron will render 0.40 to 50 per cent. of zinc insoluble.

**The Roast-Reaction Process.**—The reactions are formulated as:



In the Huntington-Heberlein process the following reaction takes place:



The first reaction given above was found to be reversible and to lead to an equilibrium; the following being the reaction tensions of the  $\text{SO}_2$ :

600°C	30 mm. Hg.
650°C	143 mm. Hg.
700°C	442 mm. Hg.
725°C	735 mm. Hg.

The activity of the reaction varies very considerably in a small range of temperature, and at any temperature within this range is dominated very strongly by the partial pressure of the  $\text{SO}_2$ .

The second reaction was also found reversible with equilibrium under the following conditions of  $\text{SO}_2$  tension:

700°C	10 mm. Hg.
750°C	35 mm. Hg.
800°C	99 mm. Hg.
825°C	286 mm. Hg.
850°C	550 mm. Hg.
875°C	850 mm. Hg.

This second reaction takes practically 150° higher temperature to make it go than the first. At 800°, PbS showed signs of volatilizing, and at higher temperatures vaporized rapidly. Also, the metallic lead formed in these reactions can dissolve PbS in the melted state, and this solubility interferes or disturbs the normal course of the reactions to some extent.

The third reaction possesses no equilibrium temperature up to pressures of  $\text{SO}_2$  of one atmosphere; it is possible, however, that such occurs for higher pressures. As it is, from 550° on the reaction proceeds irreversibly. The same is true of the fourth reaction.

In roasting  $\text{PbS}$  the concentration of the  $\text{SO}_2$  has a great influence on the product; from  $600^\circ$  and pressure of 30 mm. to  $720^\circ$  and pressure of 760 mm.,  $\text{PbSO}_4$  tends to form; at lower tensions of  $\text{SO}_2$  at these temperatures  $\text{PbO}$  forms; from  $700^\circ$  at tensions of  $\text{SO}_2$  below 100 mm.  $\text{Pb}$  forms, and above  $880^\circ$   $\text{Pb}$  forms with any tensions of  $\text{SO}_2$ .

### Speiss Treatment

The treatment of speiss, has always been a complicated problem. CLARENCE P. LINVILLE gives a resumé of a successful method of treatment used by the A.S. & R. Co. (*Min. and Met.*, January, 1926). The speiss carried 30.1 per cent.  $\text{Cu}$ ; 21.4  $\text{Pb}$ ; 10.0  $\text{Fe}$ ; 9.1  $\text{NiCo}$ ; 18.7  $\text{As}$ ; 4.6  $\text{Sb}$ ; 3.4  $\text{S}$ ; 2.1  $\text{Zn}$ , etc.;  $\text{Ag}$  and  $\text{Au}$  201.76 oz. p.t. This was crushed to  $-1$  in., mixed with 20 per cent. of its weight of sulphur and charged into a magnesite-bottomed, oil-fired reverberatory. The mixture of speiss and matte thus formed runs into the body of the furnace, from which it is tapped into slag pots, cooled and the speiss and matte broken apart. About 70 to 80 per cent. of the sulphur is used, and some arsenic is driven off, but over 90 per cent. of the arsenic will be found in the concentrated speiss. The limit of concentration is reached at about 45 per cent. combined arsenic and antimony. The order of removal of metals from the speiss is  $\text{Pb}$ ,  $\text{Cu}$ ,  $\text{Fe}$ ,  $\text{Co}$ ,  $\text{Ni}$ .

To roast the concentrated nickel speiss to drive off arsenic usually leaves too much arsenic present to admit of easy recovery of the heavy metals. Therefore it was found best to grind the speiss fine and mix with sufficient soda-ash to combine with all the arsenic and sulphur present and part of the antimony. Under a low temperature oxidizing roast, all the sulphur is converted to sodium sulphate, all the arsenic to tri-sodium arsenate, and a portion of the antimony to sodium antimoniate, while the metals present are completely converted to oxides. If now the roast product is leached with water, the soluble sodium sulphate and tri-sodium arsenate dissolve and can be almost completely removed by settling and filtration from the residue of metal oxides and sodium antimoniate, which is insoluble in water.

When attempting to get a high-grade tri-sodium arsenate from such material, we found that the sodium sulphate present was an interfering material, which crystallized with the tri-sodium arsenate. To get rid of sulphur, it was necessary to give a preliminary oxidizing roast; which removed part of the arsenic from the speiss and almost all of the sulphur. This roast is not necessary except for the removal of sulphur, as the arsenic can be completely removed by soda roasting even when large amounts of sulphur are present.

**Production of Tri-sodium Arsenate.**—The sodium arsenate is extremely soluble, but at the same time much of the insoluble speiss residue is of a colloidal nature, rendering it

difficult to settle or filter. The proper method of handling the solution and washing would be to use Dorr thickeners and wash counter-current, drawing the almost saturated clear solution of tri-sodium arsenate from one end, and underflowing completely washed speiss residue from the other. It was found that the solution of tri-sodium arsenate always was slightly colored with copper, even though the reaction was alkaline; this gave a decided green color to the crystals made. This trouble was overcome by using sodium sulphide in the clear solution. The amount necessary was extremely small, not over 1 or 2 lb. per ton of speiss. The copper could not be removed by adding the sodium sulphide to the mixture in the dissolving tank, but was very efficient when added to the clear solution. The precipitated copper sulphide had to be removed by filtration, but it took considerable time to fill a press. The clarified copper-free solution was run to a storage tank, from which it was fed by gravity to the evaporating pans. The pans were filled and refilled until finally each would be about half full of a heavy syrupy liquid, which was tested by pouring a small sample upon a clean iron plate; if it set up solid within a minute or so, the charge was considered finished and was run out into drums. After standing for about 24 hr., these drums were solid and ready for shipment. The first product obtained solidified in two layers, and analysis showed that there was considerable difference between tops and bottoms.

The residue is taken, without drying, mixed to as thick a mud as can be handled, and allowed to feed into a mixer where it is mixed cold with 66° sulphuric acid in such excess that, when the mixture is heated to complete the sulphating reaction, the result will be a creamy mass thin enough to flow in a stream from the sulphating tool. This consists of a drum 8 ft. long and 4 ft. in diameter, closed at the ends, and mounted on wheels so that it can be slowly rotated. The residue-sulphuric acid mixture flows slowly and continuously in at one end, mixes with the bath of hot sulphated material in the drum, and an equal amount of completely sulphated mass flows out at the other end. The operation is continuous. The sulphated material drops into a tall cone-bottom dissolving tank, constantly agitated with air. The free sulphuric acid in the sulphate material is sufficient to keep the solution near the boiling point. The soluble metals, including the antimony, are almost instantly dissolved. On dilution, the antimony slimes out again as a white basic precipitate. The solution carrying most of the insoluble material in suspension overflows from a point near the top of the dissolving tank, and is carried to a settling and washing system. Some heavy unsulphated lumps accumulate in the dissolving tank and must be removed, from time to time, by opening a valve at the bottom of the cone and allowing the heavy material to wash out. This material is returned to process, usually to the feed to the soda-roast furnace.

Lead Roasting Furnace Dimensions<sup>1</sup>

## LONG-BEDDED HAND-ROASTING FURNACE WITH LEVEL HEARTH

	I	II	III
Length of hearth.....	60'	66'	75'
Width of hearth.....	14'	18'	14'
Hearth area, sq. ft.....	840	1056	1150
Length of grate.....	8'	7' 9"	8'
Width of grate.....	3' 4"	2' 6"	3' 6"
Grate area, sq. ft.....	14. 6 <sup>2</sup>	19. 4	28
Ratio hearth to grate area . . .	57. 5:1	54. 5:1	41:1
Space above fire bridge, length and width.....	7' 9"×2' 2"	7' 9"×2' 2"	2' 6"×1'
Space above flue bridge, length and width.....	No flue bridge	4' 2"×8"	No flue bridge
Height of fire bridge above hearth	14"	12"	20"
Height of roof above fire bridge	18"	20"	12"
Height of flue bridge above hearth	.....	6"	.....
Height of roof above flue bridge	.....	15"	.....
Depth of grate below top of bridge.....	14"	15"	17"
Character of ore.....	1½ galena ¾ pyrite	Matte Concentration	Pyritic Galena
Depth of charge near flue bridge	3-4"	.....	5"
Time ore remains in furnace, hr	32	24	24
Tons of raw ore per 24 hr.	8.1	12	9
Lb. ore roasted sq. ft. of hearth area.....	20	21 8	15 65
Character of roasted ore.....	Partly sintered	Pulverulent	Partly sintered
Per cent. S in roasted ore. . . .	12	2-5	3

Brick used. Clay brick inside, red brick or second-class clay brick.  
Average thickness of side walls. 18 to 30 in. Thickness of roof, 9-15 in.

<sup>1</sup> "Metallurgy of Lead," H. O. HOFMAN.

<sup>2</sup> Not clear how this figure is obtained.

Roasting Table<sup>1</sup>

1 kg. FeS	becomes 0.909 kg. Fe <sub>2</sub> O <sub>3</sub>
1 kg. FeS <sub>2</sub>	becomes 0.667 kg. Fe <sub>2</sub> O <sub>3</sub>
1 kg. PbS	becomes 1.268 kg. PbSO <sub>4</sub>
1 kg. CaCO <sub>3</sub>	becomes 0.560 kg. CaO
1 kg. MgCO <sub>3</sub>	becomes 0.476 kg. MgO

<sup>2</sup> INGALLS, "Metallurgy of Zinc."

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## LENGTH OF TIME CONSUMED IN BURNING HEAPS OF VARIOUS HEIGHTS<sup>1</sup>

Height in feet	Quality of ore	Sample number	Per cent. sulphur	Per cent. copper	Days burning
5	Pyrite.....	1	39	6½	54
5	Chalcopyrite.....	2	18	14.3	41
5	Bornite and pyrite.....	3	31	21.4	53
5½	.....	1	39	6.5	66
5½	.....	2	18	14.3	50
5½	.....	3	31	21.4	65
6	.....	1	39	6.5	72
6	.....	2	18	14.3	61
6	.....	3	31	21.4	74
7	.....	1	39	6.5	94
7	.....	3	31	21.4	86
7½	Copper glance and pyrite in quartz.....	4	20	23.4	54

<sup>1</sup> PETERS, "Modern Copper Smelting"

## IGNITION AND INCANDESCENCE TEMPERATURES, DEG. C., OF SOME METALLIC SULPHIDES, HEATED IN AIR<sup>1</sup>

Material	Size of grain	First notice of SO <sub>2</sub>	Incan- descence
Pyrite . . . . .	I	325	.....
	II	405	533
	III	472	.....
Pyrrhotite . . . . .	I	430	.....
	II	525	595
	III	590	.....
Nickel sulphide, Ni, 73.3 S, 26.7	I	700	.....
	II	802	.....
	III	886	.....
Cobalt sulphide..... Co, 66.37 S, 33.63	I	574	.....
	II	684	.....
	III	859	.....
Cobalt sulphide..... Co, 70.20 S, 29.80	I	514	.....
	II	751	850
	III	1019	.....
Stibnite.....	I	200	.....
	II	340	.....
	III	240	.....
Molybdenite....	I	240	.....
	II	508	.....
	III	338	.....
Cinnabar.....	I	338	.....
	II	420	.....
	III	430	.....
Chalcocite.....	I	430	.....
	II	679	.....
	III	500	.....
Bismuth sulphide..... Bi, 83.3	I	626	.....
	II	355	.....
	III	700	.....
Manganese sulphide, Mn, 61.01, Fe, 2.02, S, 33.98	I	605	.....
	II	875	.....
	III	647	.....
Argentite.....	I	647	.....
	II	810	.....
	III	573	.....
Blende.....	I	573	.....
	II	616	.....
	III	573	.....
Galena (a).....	I	573	.....
	II	616	.....
	III	616	.....
Millerite.....	I	573	.....
	II	616	.....
	III	616	.....

<sup>1</sup> HOFMAN, "General Metallurgy," p. 404

I = 0.1 mm.

II = 0.1 to 0.2 mm

III = over 0.2 mm.

(a) In oxygen.



DESULPHATIZATION OF ANHYDROUS METALLIC SULPHATES<sup>1</sup>

Metallic sulphates	Temperature of beginning of decomposition, deg. C.	Temperature of energetic decomposition, deg. C.	Products of decomposition	Remarks
$\text{Fe}_2(\text{SO}_4)_3$ .....	167	480	$\text{Fe}_2\text{O}_3 \cdot 2\text{SO}_3$ ..	Yellow brown.
$\text{Fe}_2\text{O}_3 \cdot 2\text{SO}_3$ .....	492	560	$\text{Fe}_2\text{O}_3$ .....	Red.
$\text{Bi}_2(\text{SO}_4)_3$ .....	570	639	$5\text{Bi}_2\text{O}_3 \cdot 4(\text{SO}_3)_2$ ..	White.
$\text{Al}_2(\text{SO}_4)_3$ .....	590	639	$\text{Al}_2\text{O}_3$ .....	White.
$\text{PbSO}_4$ .....	637	705	$6\text{PbO} \cdot 5\text{SO}_3$ .....	White.
$\text{CuSO}_4$ .....	653	670	$2\text{CuO} \cdot \text{SO}_3$ .....	Orange color.
$\text{MnSO}_4$ .....	699	790	$\text{Mn}_2\text{O}_3$ .....	Dark red to black.
$\text{ZnSO}_4$ .....	702	720	$3\text{ZnO} \cdot 2\text{SO}_3$ .....	White, cold and hot.
$2\text{CuO} \cdot \text{SO}_3$ .....	702	736	$\text{CuO}$ .....	Black.
$\text{NiSO}_4$ .....	702	764	$\text{NiO}$ .....	Brownish green.
$\text{CoSO}_4$ .....	720	770	$\text{CoO}$ .....	Brown to black.
$3\text{ZnO} \cdot 2\text{SO}_3$ .....	755	767	$\text{ZnO}$ .....	Hot yellow, cold white.
$\text{CdSO}_4$ .....	827	846	$5\text{CdO} \cdot \text{SO}_3$ .....	White.
$5\text{Bi}_2\text{O}_3 \cdot 4(\text{SO}_3)_2$ .....	870	890	$\text{Bi}_2\text{O}_3(?)$ .....	Yellow.
$5\text{CdO} \cdot \text{SO}_3$ .....	878	890	$\text{CdO}$ .....	Black.
$\text{MgSO}_4$ .....	890	972	$\text{MgO}$ .....	White.
$\text{Ag}_2\text{SO}_4$ .....	917	925	$\text{Ag}$ .....	Silver white.
$6\text{PbO} \cdot 5\text{SO}_3$ .....	952	962	$2\text{PbO} \cdot \text{SO}_3(?)$ •	White to yellow.
$\text{CaSO}_4$ .....	1200	.....	$\text{CaO}$ .....	White.
$\text{BaSO}_4$ .....	1510	.....	$\text{BaO}$ .....	White.

<sup>1</sup> Hofman, "General Metallurgy." For additional data on decomposition see pp. 360, 361 and 696.

## DISSOCIATION TENSIONS OF SULPHATES AT VARIOUS TEMPERATURES. EXPRESSED IN MILLIMETERS OF MERCURY

Temp., deg. C.	$\text{Fe}_2(\text{SO}_4)_3$	$\text{CuSO}_4$	$\text{Al}_2(\text{SO}_4)_3$	$2\text{CuO} \cdot \text{SO}_3$	$\text{ZnSO}_4$
550	9.8	25.5	9.8	.....	.....
600	22.8	28.7	16.0	27.6	.....
650	58.0	37.7	25.8	33.0	.....
675	94.0	50.5	34.0	.....	0.5
700	219.0	71.0	50.0	36.0	0.8
725	.....	148.0	82.0	39.0	.....
750	.....	.....	.....	46.0	7.5
775	.....	.....	.....	.....	14.5
800	.....	.....	.....	85.0	24.0

## Dissociation Temperatures of Certain Earths and Salts

The following dissociation temperatures were obtained by W. HEMPEL and C. SCHUBERT, and were determined by heating in an electric oven and determining the end points by the evolved gas volumes. The temperatures were determined with a LECHATELIER pyrometer. (See also p. 695.)

Material	Beginning of decomposition	End of decomposition
Brown iron ore.....	470-500°C.	1280°C.
Hematite.....	1250	1500
Lead peroxide.....	290	640
Potassium permanganate..	160	1400
Potassium bichromate. ....	600	1150
Lead chromate.....	500	1500
Potassium nitrate.....	400	950
Sodium nitrate.....	380	725
Spathic iron ore.....	470	880
Strontianite.....	1075	1340
Magnesite.....	350	900
Blende.....	150-175	360
Pyrite.....	480	over 1400
Copper sulphide.....	220	550
Arsenical pyrites.....	220	.....
Copper pyrites.....	.....	720°

EFFICIENCY OF ROASTING APPARATUS<sup>1</sup>

Apparatus	Lb. ore treated in 24 hr. per sq. ft. of hearth area	Character of product for blast-furnace smelting
I. Roast heaps and stalls.....	5-20	Good.
II. Reverberatory roasters:		
1. Hand furnaces.....	24-35	Fair.
2. Mechanical furnaces.		
Average conditions....	33-75	Too fine.
Special conditions.....	150	Too fine.
3. Revolving cylinders.....	128	Too fine.
III. Blast-roasting pots, range	500-900	Excellent.
Blast-roasting pots, excellent	600	Excellent.
IV. Blast-roasting, thin layers:		
Dwight-Lloyd system		
1. Intermittent down-draft pans.	1000-2000	Excellent.
2. Continuous sintering machines	2200-3000	Excellent.

<sup>1</sup> HOFMAN, "General Metallurgy," p. 433.

### Metallurgical Slags

In metallurgy, **slagging** is the formation, at elevated temperatures, of any fluid or semi-fluid mass, with the separation from it of a metal or metalloidal residue. Slags may be waste products, as in lead, iron or copper smelting in the blast furnace, or they may be extremely rich in products which must be retreated, as the slags from copper-refining furnaces or from slimes smelting.

The ordinary constituents of the metallurgist's slags may be grouped as follows:

**Bases:**  $\text{FeO}$ ,  $\text{CaO}$ ,  $\text{Cu}_2\text{O}$ ,  $\text{PbO}$ ,  $\text{MnO}$ ,  $\text{ZnO}$ ,  $\text{MgO}$ ,  $\text{BaO}$ ,  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{Al}_2\text{O}_3$  (sometimes).

**Protecting agents:** S, As, Sb, Te, Se.

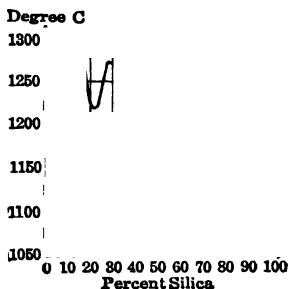
**Reducing agents:** C, S.

**Acids:**  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  (sometimes).

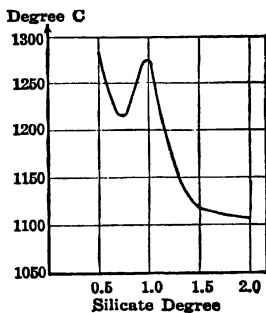
**Neutral solvents:**  $\text{CaF}_2$ ,  $\text{Na}_2\text{CO}_3$ ,  $\text{K}_2\text{CO}_3$ ,  $\text{CaCl}_2$ , borates.

**Slag Degree.**—The metallurgist names his slag by the relative amounts of oxygen combined with acid and base. Thus a bisilicate slag is  $\text{FeO} \cdot \text{SiO}_2$ , since there is twice the oxygen combined with the silica as with the iron. It follows, then, that the bisilicate of the metallurgist is the silicate of the chemist. A metallurgical monosilicate is  $(\text{FeO})_2 \cdot \text{SiO}_2$ ; a sesquisilicate  $(\text{FeO})_3 \cdot (\text{SiO}_2)_2$ .

**Iron.**—Within reasonable limits, the larger the amount of iron the more fusible the slag. Slags rich in iron are dangerous in a lead furnace, as high iron seems to promote the formation of



Formation temperatures of ferrous silicates. (HOFMAN.)

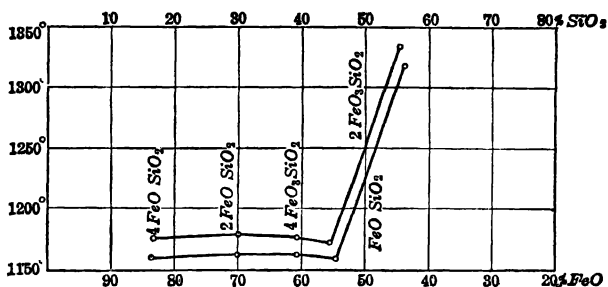


Formation temperatures of ferrous silicates. (HOFMAN.)

crusts. But high iron is considered a necessity, by some, when zinc is present, as it is said high iron promotes the solution of  $\text{ZnO}$ .

**Pyrite**—loses one atom of sulphur and enters the matte to the extent of 70 per cent. or over, except in pyritic smelting.

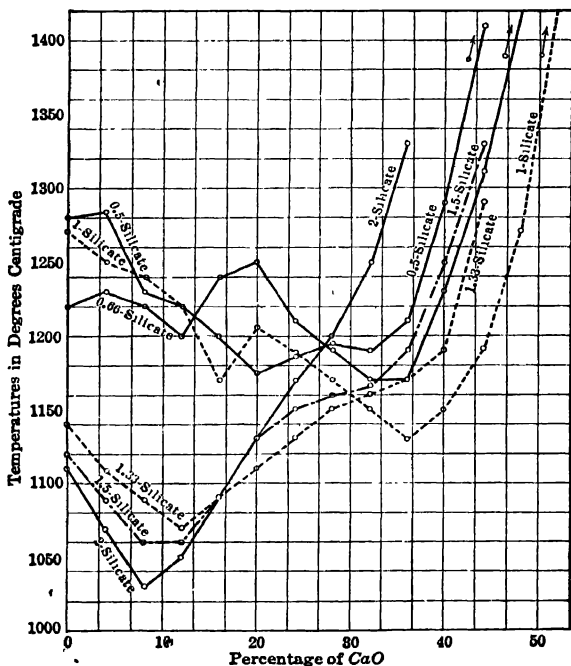
**Manganese.**—In general its effects are similar to iron, but it makes a less fusible and more liquid slag than iron. It should



Formation temperatures of ferrous silicates.

Lower line—Sintering temperatures.

Upper line—Temperatures of complete fusion.



Formation temperatures of some ferrous-calcic silicates.

be used with as acid slags as are economical. It seems to carry silver into the slag. It reduces the dissolving power of the slag for zinc oxide, magnesia and barium sulphide. The luster of an Mn slag is usually glassy and small particles are attracted by a magnet.

**Lime and Magnesia.**—Lime decreases (after a certain point) both the fusibility and the specific gravity of slags. In lead smelting it seems to inhibit the formation of speiss and matte. It is said to enter mattes as  $\text{CaS}$ . Burnt lime seems to offer no advantage over limestone. Magnesia replaces lime to a considerable extent, but magnesia and zinc are incompatibles. The Mg slags usually do not flow well.

**Fluorspar.**—Forms extremely fusible slags and will dissolve anything.

**Alumina.**—Apparently acts as a base if much silica is present, as an acid if the silica is low, always as a nuisance. In my own work it has seemed to make a most unhappy mixture with high magnesia. Some successful slags with high alumina are given on p. 706. It may be only an accident that they were successful. In iron practice, MR. MENK of the Shenango Furnace Co. has run slags carrying 18–23 per cent. of  $\text{Al}_2\text{O}_3$ , but they were tough and pasty, and coke consumption was high. On the other hand, a slag carrying 10–15 per cent. of  $\text{Al}_2\text{O}_3$  usually is a better running slag than one carrying only 7. That is, there is a lower danger line as well as an upper.

In some work done by the Bureau of Mines, slags containing up to 49.5% of  $\text{Al}_2\text{O}_3$  were produced with melting points of  $1421^\circ\text{C}$ . This slag carried  $\text{CaO}$ , 47.5;  $\text{Al}_2\text{O}_3$ , 49.5;  $\text{SiO}_2$ , 3.0. This was in an attempt to produce iron from ferruginous bauxites, using the slag as a source of aluminum. (Bureau of Mines, *Tech. Paper* 425.)

**Barium.**—It enters slag as silicate and matte as sulphide, making the former heavy, the latter light, and thereby hindering settling. A barium-iron slag is usually not very fluid, is opaque, steel gray to black, with vitreous luster, and usually is strongly magnetic.

**Blende and Zinc Oxide.**—The most successful practice with high-zinc slags is that at Cockle Creek and Port Pirie, Australia. Some of the type slags are given in the following table, together with some from Colorado practice recommended by FURMAN.

# 700 METALLURGISTS AND CHEMISTS' HANDBOOK

	C.C. 1903	P.P. 1918	P.P. 1922	P.P. 1922	P.P. 1927	Fur. 1893	Fur. 1893
SiO <sub>2</sub> . . . .	22.0	23.4	20.7	18.4	22.3	26.0	26.4
FeO . . . . .	33.5	34.4	28.0	20.3	29.6	33.4	22.7
MnO . . . . .			4.5	5.1			
CaO . . . . .	13.0	12.2	11.6	8.9	14.4	14.4	24.4
MgO . . . . .	4.0	tr	2.0	..			
Al <sub>2</sub> O <sub>3</sub> . . . .	8.0	5.0	6.2	..	6.3	19.8	21.0
ZnO . . . . .	14.5	20.1	20.9	33.3	21.8		
S . . . . .	3.0	2.5	2.7	....	2.1		
Cu . . . . .	..	..	0.19				
As, Sb . . . .	..	..	0.07				
Cl . . . . .	..	..	0.08				
Pb . . . . .	1.2	1.5					

Clean roasting is a necessity in these high-zinc slags. As the zinc increases the lime and silica must be cut. If the slag carries over 3½ or 4 per cent. S, zinc mush makes its appearance.

PHILIP S. MORSE, in commenting on these high-zinc slags (*Proc. A.I.M.E.*, February meeting, 1929) says that iron is undoubtedly a carrier of zinc and believes that the zinc oxide goes off as iron and alumina spinels. G. C. STONE states that these slags were calculated on the O of the zinc being one-third that of the O in Fe<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>O<sub>3</sub>, and the O of the SiO<sub>2</sub> equal to the O of the MgO, CaO and MnO.

**Silicon.**—While the problem of the non-ferrous metallurgist is ordinarily only that of getting rid of the silica as a fusible slag, the iron smelter has the additional one of controlling the amount of silicon in his product. Since the reduction temperature of silicon is higher than that of iron, higher temperatures are necessary to secure increasing silicon. As a corollary it then follows that to raise the temperature of the slag (by addition of alumina preferably) will raise the amount of silicon in the iron.

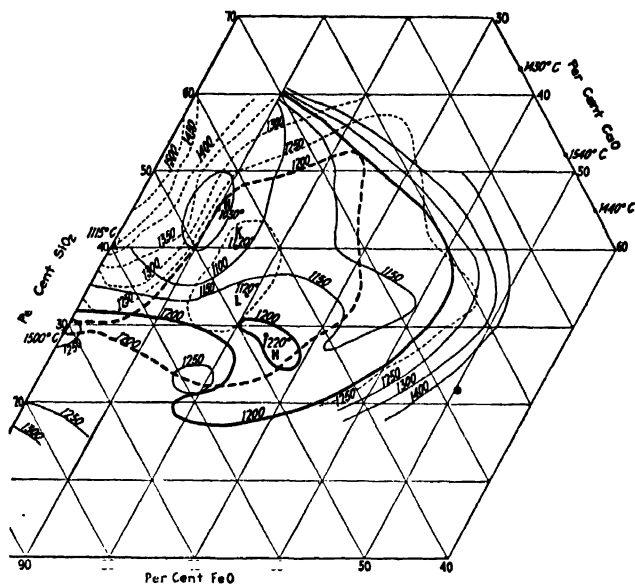
In iron practice the addition of magnesia will often lower the melting point of the slag and decrease the silicon in the iron. This is particularly important in the manufacture of basic pig.

**Phosphorus.**—In iron practice it may be safely assumed that 100 per cent. will enter the iron, but in matte smelting it appears that over half will enter the slag.

**Arsenic, Antimony, Selenium and Tellurium.**—Tend to form speiss; are of more trouble in the subsequent refining than in smelting, except in so far as they volatilize easily and tend to carry off other metals.

**Fusion Temperatures of Ferrous-calcium Silicates.**—The data on the fusion temperatures of ferrous-calcium silicates are conflicting.

The accompanying illustration shows the two best sets of data plotted on one triaxial diagram. The full lines represent the fusion temperatures according to Hofman and Babu, *Trans.*



Formation temperatures of Ferrous-Calcium Silicates

A.I.M.E., Vol. 29, 682; the dotted lines according to Kern and Loo, *Trans. A.I.M.E.*, Vol. 76, pp. 494-522.

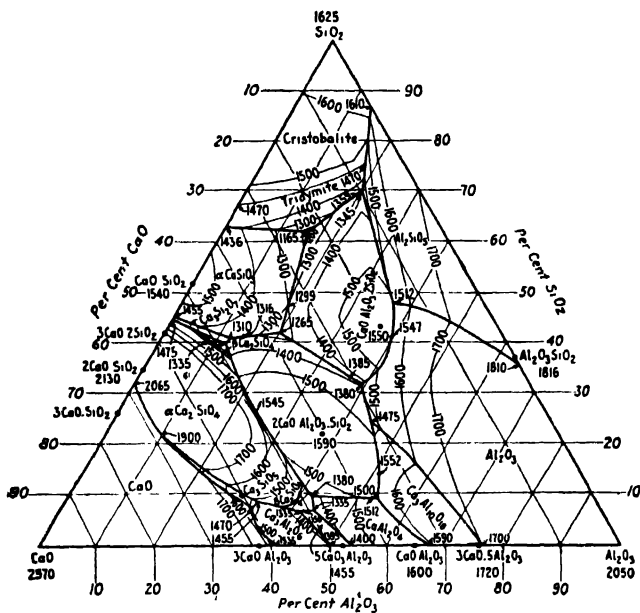
There are certain temperatures marked "C." While the temperatures are "centigrade," the "C's" stand for Campbell, who determined these isolated points. The numbers along the lines are degrees Centigrade.

It is probable that much of the discrepancy in these results comes in as a result of the oxidation of some of the  $\text{FeO}$  to  $\text{Fe}_2\text{O}_3$ , gives a quaternary system instead of a ternary.

In general, the use of additional bases will lower the melting point of a slag. Thus, in a ferrous-calcium silicate, the replacement of a portion of the iron by manganese, or of a portion of

the calcium by magnesium, or by barium, will result in a more fusible slag.

**Copper Losses in Slag.**—An interesting series of articles by



CaO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> Melting point diagram.

FRANK E. LATHE was published on this subject in the *Engineering and Mining Journal* of Aug. 7, 14 and 21, 1915, to which reference should be made for complete data. In general, however, the conclusions that he appears to consider well founded were that the loss of copper in the slag increases directly with increasing matte tenor; that the loss in the slag decreases directly as increasing silica tenor, unless the matte be over 50 per cent. Cu; that probably 50 per cent. of the copper lost was as oxide and was due to overoxidation; that slags containing a large amount of metal with a high affinity for sulphur were likely to carry considerable copper (this would account for the effect Mn is sometimes supposed to have on a slag).



Specific Gravities of Slag-forming Compounds.<sup>1</sup>

Singulo-silicates of iron, manganese and zinc, about 4.

Bisilicates of iron, manganese and zinc, about 3.5.

The basic silicates of alumina, from 3.2 to 3.4.

The acid silicates of alumina, from 3 to 3.2.

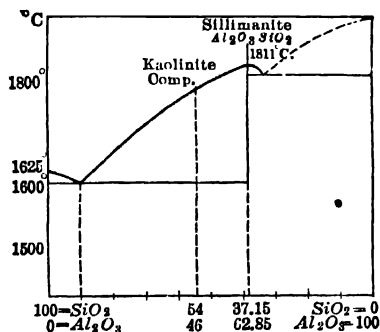
Silicates of magnesia, from 3 to 3.3. Silicates of lime, from 2.6 to 3.

Alkaline silicates, about 2.5. Uncombined silica, 2.6.

Bisilicate of barium, 4.4. Silicate of lead, 7.

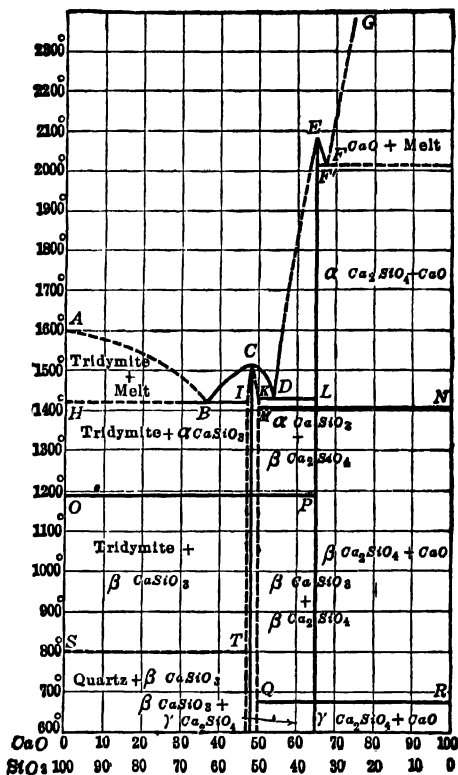
Ferrous sulphide, 4.8. Calcium sulphide, 4.

Magnetic oxide, 5. Sulphate of barium, 4.5.

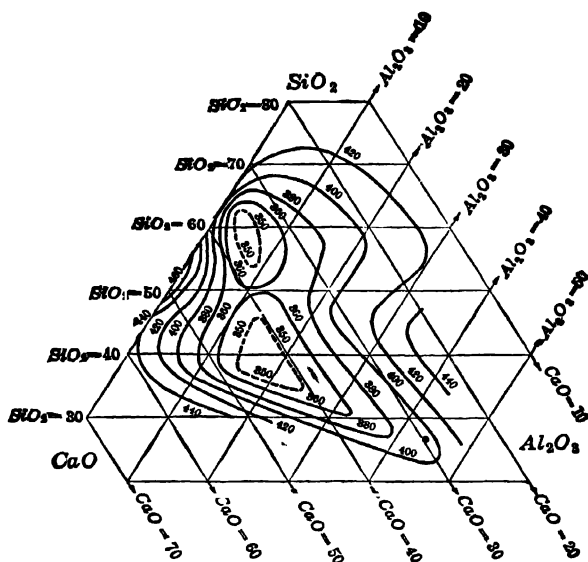


Formation temperatures,  $Al_2O_3$ - $SiO_2$  series  
(After SHEPHERD and RANKINE)

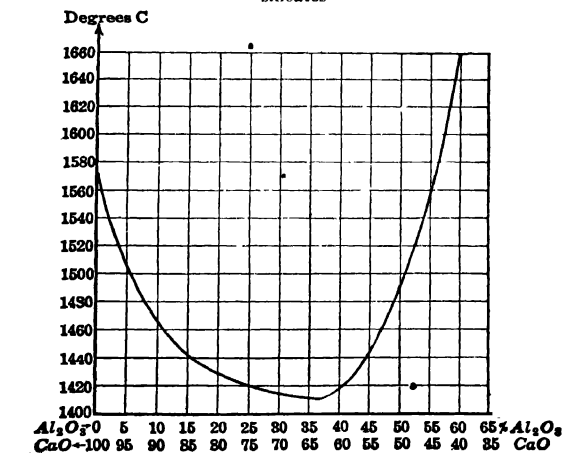
<sup>1</sup> HOFMAN'S "General Metallurgy," p 74



Freezing temperatures,  $\text{CaO}-\text{SiO}_2$  series.  
(After SHEPHERD and DAY.)



Triaxial diagram of total heats of solidification of calcium-aluminum silicates



Formation temperatures of the calcium-aluminum singulo-silicates.

## SULPHIDES

Given	Required	Factor	Given	Required	Factor
Cu	Cu <sub>2</sub> S	1.252	FeS <sub>2</sub>	S (total)	0.5342
Cu	S (to make Cu <sub>2</sub> S)	0.2520	FeS <sub>2</sub>	FeS (FeS <sub>2</sub> = FeS + S)	0.7329
Cu <sub>2</sub> S	Cu	0.7987	Pb	PbS	1.155
Cu <sub>2</sub> S	S	0.2013	PbS	Pb	0.8658
Fe	FeS	1.574	PbS	Fe (PbS + Fe = FeS + Pb)	0.2339
Fe	S (to make FeS)	0.5735	S	Cu (to make Cu <sub>2</sub> S)	3.968
FeS	Fe	0.6355	S	Cu <sub>2</sub> S	4.968
FeS	S	0.3645	S	FeS	2.744
FeS	Fe <sub>2</sub> O <sub>3</sub>	0.9084	S	Fe <sub>2</sub> O <sub>3</sub> (required for FeS)	2.493

## ALUMINA SLAGS (ACCORDING TO HENRICH)

	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	FeO	CaO
"Singulo" slag (FeO) <sub>4</sub> (CaO) <sub>4</sub> (Al <sub>2</sub> O <sub>3</sub> ) <sub>2</sub> (SiO <sub>2</sub> ) <sub>4</sub>	16.05	18.22	25.73	40.00
"Sesqui" slag (FeO) <sub>4</sub> (CaO) <sub>4</sub> (Al <sub>2</sub> O <sub>3</sub> ) <sub>2</sub> (SiO <sub>2</sub> ) <sub>4</sub>	27.15	15.31	32.32	25.22
"Bi" slag (FeO) <sub>4</sub> (CaO) <sub>4</sub> (Al <sub>2</sub> O <sub>3</sub> ) <sub>2</sub> (SiO <sub>2</sub> ) <sub>4</sub> . . . . .	35.12	13.21	37.17	14.50

SOME PYRITIC SLAGS<sup>1</sup>

Made by	SiO <sub>2</sub>	Fe	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	Ag	Cu
Walter E. Koch. . . . .	41-45	27-31	5-7	5-15	2-5	....	....
F. R. Carpenter . . . . .	33.5	32.26	2.00	11.42	....	....	0.2
W. H. Nutting . . . . .	44.0	28.0	1. . .	18.0	....	0.24	0.27
W. H. Freeland . . . . .	32.60	38.84	1.54	8.24	3.44	....	0.35
Wm. A. Heywood . . . . .	31.04	51.40	4.84	6.30	1.37	....	0.4

<sup>1</sup> T. A. RICKARD'S "Pyritic Smelting"

**Metallurgical Factors<sup>1</sup>****ORTHOSILICATE SLAGS**

To use the tables on page 708 for metasilicates,  $\text{CaSiO}_3$ ,  $\text{Na}_2\text{SiO}_3$ , etc., double the amount of silica found in the table.

To use it for mesosilicates  $(\text{CaO})_3 (\text{SiO}_2)_2$ ,  $(\text{Na}_2)_3 (\text{SiO}_2)_2$ , etc., increase by one-third the amount of silica in the table.

**ORTHOSILICATE SLAG FACTORS**

Given	Re- quired	To make	Factor	Given	Re- quired	To make	Factor
$\text{Al}_2\text{O}_3$	$\text{SiO}_2$	$\text{Al}_4(\text{SiO}_4)_3$	0.8865	$\text{FeS}$	$\text{SiO}_2$	$\text{Fe}_2\text{SiO}_4$	0.3433
$\text{BaO}$	$\text{SiO}_2$	$\text{Ba}_2\text{SiO}_4$	0.1969	$\text{FeS}_2$	$\text{SiO}_2$	$\text{Fe}_3\text{SiO}_4$	0.2516
$\text{BaSO}_4$	$\text{SiO}_2$	$\text{Ba}_2\text{SiO}_4$	0.1294	$\text{K}_2\text{O}$	$\text{SiO}_2$	$\text{K}_4\text{SiO}_4$	0.3203
$\text{CaO}$	$\text{SiO}_2$	$\text{Ca}_2\text{SiO}_4$	0.5383	$\text{MgO}$	$\text{SiO}_2$	$\text{Mg}_2\text{SiO}_4$	0.7483
$\text{CaCO}_3$	$\text{SiO}_2$	$\text{Ca}_2\text{SiO}_4$	0.3017	$\text{MgCO}_3$	$\text{SiO}_2$	$\text{Mg}_2\text{SiO}_4$	0.3580
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	$\text{SiO}_2$	$\text{Ca}_2\text{SiO}_4$	0.1754	$\text{Mn}$	$\text{SiO}_2$	$\text{Mn}_2\text{SiO}_4$	0.5491
$\text{Cu}$	$\text{SiO}_2$	$\text{Cu}_4\text{SiO}_4$	0.2374	$\text{MnO}$	$\text{SiO}_2$	$\text{Mn}_2\text{SiO}_4$	0.4254
$\text{CuO}$	$\text{SiO}_2$	$\text{Cu}_4\text{SiO}_4$	0.1897	$\text{Na}_2\text{O}$	$\text{SiO}_2$	$\text{Na}_4\text{SiO}_4$	0.4863
$\text{Fe}$	$\text{SiO}_2$	$\text{Fe}_2\text{SiO}_4$	0.5403	$\text{Pb}$	$\text{SiO}_2$	$\text{Pb}_2\text{SiO}_4$	0.1460
$\text{FeO}$	$\text{SiO}_2$	$\text{Fe}_2\text{SiO}_4$	0.4200	$\text{PbO}$	$\text{SiO}_2$	$\text{Pb}_2\text{SiO}_4$	0.1355
$\text{Fe}_2\text{O}_3$	$\text{SiO}_2$	$\text{Fe}_2\text{SiO}_4$	0.3780	$\text{Zn}$	$\text{SiO}_2$	$\text{Zn}_2\text{SiO}_4$	0.4618
$\text{Fe}_3\text{O}_4$	$\text{SiO}_2$	$\text{Fe}_2\text{SiO}_4$	0.3910	$\text{ZnO}$	$\text{SiO}_2$	$\text{Zn}_2\text{SiO}_4$	0.3710

To use the following table for metasilicates,  $(\text{M}'\text{SiO}_3)$  halve the amount of basic substance found by the table.

To use it for mesosilicates,  $(\text{M}'\text{O})_3 (\text{SiO}_2)_2$  decrease by one-quarter the amount found by the table.

$\text{SiO}_2$	$\text{Al}_2\text{O}_3$	$\text{Al}_4(\text{SiO}_4)_3$	1.128	$\text{SiO}_2$	$\text{K}_2\text{CO}_3$	$\text{K}_4\text{SiO}_4$	4.579
$\text{SiO}_2$	$\text{BaO}$	$\text{Ba}_2\text{SiO}_4$	5.080	$\text{SiO}_2$	$\text{MgO}$	$\text{Mg}_2\text{SiO}_4$	1.336
$\text{SiO}_2$	$\text{BaSO}_4$	$\text{Ba}_2\text{SiO}_4$	7.730	$\text{SiO}_2$	$\text{MgCO}_3$	$\text{Mg}_2\text{SiO}_4$	2.793
$\text{SiO}_2$	$\text{CaO}$	$\text{Ca}_2\text{SiO}_4$	1.858	$\text{SiO}_2$	$\text{Mn}$	$\text{Mn}_2\text{SiO}_4$	1.821
$\text{SiO}_2$	$\text{CaCO}_3$	$\text{Ca}_2\text{SiO}_4$	3.315	$\text{SiO}_2$	$\text{MnO}$	$\text{Mn}_2\text{SiO}_4$	2.351
$\text{SiO}_2$	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	$\text{Ca}_2\text{SiO}_4$	5.702	$\text{SiO}_2$	$\text{Na}_2\text{CO}_3$	$\text{Na}_4\text{SiO}_4$	3.513 <sup>*</sup>
$\text{SiO}_2$	$\text{Cu}$	$\text{Cu}_4\text{SiO}_4$	4.212	$\text{SiO}_2$	$\text{Pb}$	$\text{Pb}_2\text{SiO}_4$	6.851
$\text{SiO}_2$	$\text{CuO}$	$\text{Cu}_4\text{SiO}_4$	5.271	$\text{SiO}_2$	$\text{PbO}$	$\text{Pb}_2\text{SiO}_4$	7.381
$\text{SiO}_2$	$\text{Fe}$	$\text{Fe}_2\text{SiO}_4$	1.851	$\text{SiO}_2$	$\text{Zn}$	$\text{Zn}_2\text{SiO}_4$	2.166
$\text{SiO}_2$	$\text{FeO}$	$\text{Fe}_2\text{SiO}_4$	2.381	$\text{SiO}_2$	$\text{ZnO}$	$\text{Zn}_2\text{SiO}_4$	2.695
$\text{SiO}_2$	$\text{Fe}_2\text{O}_3$	$\text{Fe}_2\text{SiO}_4$	2.646				
$\text{SiO}_2$	$\text{Fe}_3\text{O}_4$	$\text{Fe}_2\text{SiO}_4$	2.557				
$\text{SiO}_2$	$\text{FeS}$	$\text{Fe}_2\text{SiO}_4$	2.913				
$\text{SiO}_2$	$\text{FeS}_2$	$\text{Fe}_2\text{SiO}_4$	3.974				

<sup>1</sup> From H. L. WELL'S "Chemical Calculations," Henry Holt & Co., New York.

# 708 METALLURGISTS AND CHEMISTS' HANDBOOK

## BALLING'S TABLES FROM "COMPENDIUM DER METALLURGISCHEN CHEMIE"

One part by weight of silica requires	Parts by weight of bases	One part by weight of bases requires	Parts by weight of silica
For Singulo-silicates		For Singulo-silicates	
Lime.....	1.86	Lime.....	0.538
Magnesia.....	1.34	Magnesia.....	0.748
Alumina.....	1.13	Alumina.....	0.886
Ferrous oxide.....	2.38	Ferrous oxide.....	0.420
Manganous oxide.....	2.35	Manganous oxide....	0.425
For Bi-silicates		For Bi-silicates	
Lime.....	0.93	Lime.....	1.077
Magnesia.....	0.67	Magnesia.....	1.497
Alumina.....	0.56	Alumina.....	1.773
Ferrous oxide.....	1.19	Ferrous oxide.....	0.841
Manganous oxide.....	1.18	Manganous oxide....	0.851
For Sesqui-silicates		For Sesqui-silicates	
Lime.....	1.24	Lime.....	0.806
Magnesia.....	0.89	Magnesia.....	1.122
Alumina.....	0.75	Alumina.....	1.330
Ferrous oxide.....	1.59	Ferrous oxide.....	0.630
Manganous oxide.....	1.57	Manganous oxide....	0.638

### BALLING'S TABLE FOR ALUMINA AS ACID

To form  $(\text{MO})_3\text{Al}_2\text{O}_3$

1 part $\text{Al}_2\text{O}_3$ requires parts of		1 part of base requires parts $\text{Al}_2\text{O}_3$	
MgO.....	1.72	MgO.....	0.580
CaO.....	2.47	CaO.....	0.417
MnO.....	3.03	MnO.....	0.330
FeO.....	3.07	FeO.....	0.325
ZnO.....	3.48	ZnO.....	0.287
BaO.....	6.56	BaO.....	0.153
$\text{Na}_2\text{O}$ .....	2.65	$\text{Na}_2\text{O}$ .....	0.377
$\text{K}_2\text{O}$ .....	4.03	$\text{K}_2\text{O}$ .....	0.248

## I. AUXILIARY TABLES TO ACCOMPANY BALLING'S SLAG TABLE

Formula	Mol. wt.	Log.
(MgO) <sub>4</sub> SiO <sub>2</sub> .....	221.84	2.34604
(CaO) <sub>4</sub> SiO <sub>2</sub> .....	284.8	2.45454
(MnO) <sub>4</sub> SiO <sub>2</sub> .....	344.4	2.53706
(FeO) <sub>4</sub> SiO <sub>2</sub> .....	348.0	2.54158
(BaO) <sub>4</sub> SiO <sub>2</sub> .....	674.0	2.82866
(MgO) <sub>3</sub> SiO <sub>2</sub> .....	181.48	2.25883
(CaO) <sub>3</sub> SiO <sub>2</sub> .....	228.7	2.35927
(MnO) <sub>3</sub> SiO <sub>2</sub> .....	273.4	2.43680
(FeO) <sub>3</sub> SiO <sub>2</sub> .....	276.1	2.44107
(BaO) <sub>3</sub> SiO <sub>2</sub> .....	520.6	2.71650
(MgO) <sub>2</sub> SiO <sub>2</sub> .....	141.12	2.14959
(CaO) <sub>2</sub> SiO <sub>2</sub> .....	172.6	2.23704
(MnO) <sub>2</sub> SiO <sub>2</sub> .....	202.4	2.30621
(FeO) <sub>2</sub> SiO <sub>2</sub> .....	204.2	2.31006
(BaO) <sub>2</sub> SiO <sub>2</sub> .....	367.2	2.56490
(MgO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	342.64	2.53484
(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	405.6	2.60810
(MnO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	465.2	2.66755
(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	468.8	2.67099
(BaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	794.8	2.90026
MgOSiO <sub>2</sub> .....	100.76	2.00329
CaOSiO <sub>2</sub> .....	116.5	2.06633
MnOSiO <sub>2</sub> .....	131.4	2.11860
FeOSiO <sub>2</sub> .....	132.3	2.12156
BaOSiO <sub>2</sub> .....	213.8	2.33001

## II. RATIOS OF MOLECULAR WEIGHTS

CaSiO <sub>3</sub>	FeSiO <sub>3</sub>	Fe <sub>4</sub> Si <sub>3</sub> O <sub>10</sub>	Fe <sub>2</sub> SiO <sub>4</sub>
1.000	1.136	4.024	1.757
Ca <sub>4</sub> Si <sub>3</sub> O <sub>10</sub>	Fe <sub>4</sub> Si <sub>3</sub> O <sub>10</sub>	Fe <sub>2</sub> SiO <sub>4</sub>	Fe <sub>3</sub> SiO <sub>5</sub>
1.000	1.156	0.5035	0.6807
Ca <sub>2</sub> SiO <sub>4</sub>	Fe <sub>2</sub> SiO <sub>4</sub>	Fe <sub>3</sub> SiO <sub>5</sub>	Fe <sub>4</sub> SiO <sub>8</sub>
1.000	1.183	1.600	2.016
CaSiO <sub>3</sub>	Ca <sub>4</sub> Si <sub>3</sub> O <sub>10</sub>	Ca <sub>2</sub> SiO <sub>4</sub>	.....
1.000	3.483	1.482	.....

FeSiO <sub>3</sub>	Fe <sub>4</sub> Si <sub>3</sub> O <sub>4</sub>	Fe <sub>2</sub> SiO <sub>4</sub>	Fe <sub>3</sub> SiO <sub>5</sub>	Fe <sub>4</sub> SiO <sub>8</sub>
1.00	3.543	1.543	2.087	2.630

## 710 METALLURGISTS AND CHEMISTS' HANDBOOK

## III. BASES

Radical	Mol. wt.	Log.
MgO.....	40.36	1.60595
CaO.....	56.1	1.74896
Na <sub>2</sub> O.....	62.1	1.79309
MnO.....	71.0	1.85126
FeO.....	71.9	1.85673
K <sub>2</sub> O.....	94.3	1.97451
SrO.....	103.6	2.01536
ZnO.....	106.6	2.02776
Cu <sub>2</sub> O.....	143.2	2.15594
BaO.....	153.4	2.18583
PbO.....	222.7	2.34772

## ACIDS

Radical	Mol. wt.	Log.
Al <sub>2</sub> O <sub>3</sub> .....	102.2	2.00945
B <sub>2</sub> O <sub>3</sub> .....	70.0	1.84510
P <sub>2</sub> O <sub>5</sub> .....	142.0	2.15229
SiO <sub>2</sub> .....	60.4	1.78104
TiO <sub>2</sub> .....	80.1	1.90363



IV. COMPOSITION OF TYPE SLAGS  
 (Calculated to a 90 per cent. total)

Compound	SiO <sub>2</sub>	FeO	CaO
FeO·SiO <sub>2</sub> .....	41.1	48.9	.....
4(FeO·SiO <sub>2</sub> ) + CaO·SiO <sub>2</sub> .....	42.1	40.1	7.8
3(FeO·SiO <sub>2</sub> ) + CaO·SiO <sub>2</sub> .....	42.4	37.8	9.8
2(FeO·SiO <sub>2</sub> ) + CaO·SiO <sub>2</sub> .....	42.8	34.0	13.2
3(FeO·SiO <sub>2</sub> ) + 2(CaO·SiO <sub>2</sub> ).....	43.2	30.8	16.0
FeO·SiO <sub>2</sub> + CaO·SiO <sub>2</sub> .....	43.6	26.1	20.3
2(FeO·SiO) + 3(CaO·SiO <sub>2</sub> ).....	44.2	21.1	24.7
FeO·SiO <sub>2</sub> + 2(CaO·SiO <sub>2</sub> ).....	44.7	17.7	27.6
FeO·SiO <sub>2</sub> + 3(CaO·SiO <sub>2</sub> ).....	45.2	13.4	31.4
FeO·SiO <sub>2</sub> + 4(CaO·SiO <sub>2</sub> ).....	45.4	10.8	33.8
CaO·SiO <sub>2</sub> .....	46.7	.....	43.3
(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	34.8	55.2	.....
4(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + CaO·SiO <sub>2</sub> .....	35.5	52.0	2.5
3(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + 2CaO·SiO <sub>2</sub> .....	36.4	47.4	6.2
(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + CaO·SiO <sub>2</sub> .....	37.2	44.2	8.6
2(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + 3CaO·SiO <sub>2</sub> .....	38.1	40.2	11.7
(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + 4CaO·SiO <sub>2</sub> .....	40.9	27.5	21.6
CaO·SiO <sub>2</sub> .....	46.7	.....	43.3
(FeO) <sub>2</sub> SiO <sub>2</sub> .....	26.6	63.4	.....
4(FeO) <sub>2</sub> SiO <sub>2</sub> + CaO·SiO <sub>2</sub> .....	29.1	55.5	5.4
3(FeO) <sub>2</sub> SiO <sub>2</sub> + 2CaO·SiO <sub>2</sub> .....	32.2	45.9	11.9
(FeO) <sub>2</sub> SiO <sub>2</sub> + CaO·SiO <sub>2</sub> .....	33.9	40.4	15.7
2(FeO) <sub>2</sub> SiO <sub>2</sub> + CaO·SiO <sub>2</sub> .....	35.8	34.2	20.0
(FeO) <sub>2</sub> SiO <sub>2</sub> + 4CaO·SiO <sub>2</sub> .....	40.6	19.3	30.1
CaO·SiO <sub>2</sub> .....	46.7	.....	43.3

	SiO <sub>2</sub>	FeO <sub>2</sub>	CaO
(FeO) <sub>2</sub> SiO <sub>2</sub> .....	26.6	63.4	.....
4(FeO) <sub>2</sub> SiO <sub>2</sub> + (CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	31.1	42.4	16.5
3(FeO) <sub>2</sub> SiO <sub>2</sub> + 2(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	34.3	27.3	28.4
(FeO) <sub>2</sub> SiO <sub>2</sub> + (CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	35.7	21.2	33.1
2(FeO) <sub>2</sub> SiO <sub>2</sub> + 3(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	36.8	15.9	37.3
(FeO) <sub>2</sub> SiO <sub>2</sub> + 4(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	38.7	7.1	44.2
(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	40.2	.....	49.8
(FeO) <sub>2</sub> SiO <sub>2</sub> .....	26.6	63.4	.....
4(FeO) <sub>2</sub> SiO <sub>2</sub> + (CaO) <sub>2</sub> SiO <sub>2</sub> .....	27.5	52.3	10.2
3(FeO) <sub>2</sub> SiO <sub>2</sub> + (CaO) <sub>2</sub> SiO <sub>2</sub> .....	27.7	49.4	12.9
2(FeO) <sub>2</sub> SiO <sub>2</sub> + (CaO) <sub>2</sub> SiO <sub>2</sub> .....	28.1	44.5	17.4
3(FeO) <sub>2</sub> SiO <sub>2</sub> + 2(CaO) <sub>2</sub> SiO <sub>2</sub> .....	28.4	40.5	21.1
(FeO) <sub>2</sub> SiO <sub>2</sub> + (CaO) <sub>2</sub> SiO <sub>2</sub> .....	28.9	34.3	26.8
2(FeO) <sub>2</sub> SiO <sub>2</sub> + 3(CaO) <sub>2</sub> SiO <sub>2</sub> .....	29.4	27.9	32.7
(FeO) <sub>2</sub> SiO <sub>2</sub> + 2(CaO) <sub>2</sub> SiO <sub>2</sub> .....	29.6	23.6	36.8
(FeO) <sub>2</sub> SiO <sub>2</sub> + 3(CaO) <sub>2</sub> SiO <sub>2</sub> .....	30.1	17.9	42.0
(FeO) <sub>2</sub> SiO <sub>2</sub> + 4(CaO) <sub>2</sub> SiO <sub>2</sub> .....	30.4	14.4	45.2
(CaO) <sub>2</sub> SiO <sub>2</sub> .....	31.5	.....	58.5

	SiO <sub>2</sub>	FeO	CaO
(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	34.8	55.2	.....
4(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + (CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	35.7	45.4	8.9
3(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + (CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	36.0	42.9	11.1
2(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + (CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	36.6	38.4	15.0
3(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + 2(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	36.7	35.1	18.2
(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + (CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	37.3	29.6	23.1
2(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + 3(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	37.9	24.0	28.1
(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + 2(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	38.2	20.2	31.6
(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + 3(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	38.7	15.4	35.9
(FeO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> + 4(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	39.0	12.4	38.6
(CaO) <sub>4</sub> (SiO <sub>2</sub> ) <sub>3</sub> .....	40.2	.....	49.8

### Formation Temperature of Some Pure Ferrous Silicates

4FeO, SiO <sub>2</sub>	= 82.8 % FeO, 17.2 % SiO <sub>2</sub>	= 1280°C. <sup>1</sup>
3FeO, 2SiO <sub>2</sub>	= 64.3 % FeO, 35.7 % SiO <sub>2</sub>	= 1140°C. <sup>1</sup>
FeO, SiO <sub>2</sub>	= 54.55 % FeO, 45.45 % SiO <sub>2</sub>	= 1110°C. <sup>1</sup>
2CaO, SiO <sub>2</sub>	= 65.0 % CaO, 35.0 % SiO <sub>2</sub>	= 1570°C. <sup>2</sup>
CaO, SiO <sub>2</sub>	= 48.2 % CaO, 51.8 % SiO <sub>2</sub>	= 1540°C. <sup>2</sup>
3CaO, 2SiO <sub>2</sub>	= 58.2 % CaO, 41.8 % SiO <sub>2</sub>	= dissociates at 1475°C. <sup>3</sup>
3CaO, SiO <sub>2</sub>	= 73.6 % CaO, 26.4 % SiO <sub>2</sub>	= dissociates at 1900°, before melting <sup>3</sup>
4CaO, 3SiO <sub>2</sub>	= 37.0 % CaO, 63.0 % SiO <sub>2</sub>	= 1436°C. <sup>3</sup>
4CaO, 3SiO <sub>2</sub>	= 64.5 % CaO, 45.5 % SiO <sub>2</sub>	= 1455°C. <sup>3</sup>

<sup>1</sup> Trans. A.I.M.E., Vol. 29.

<sup>2</sup> F. T. HAVARD, "Furnaces and Refractories."

<sup>3</sup> RANKIN and WRIGHT, *Am. Journ. Sci.*, January, 1915.

### FORMATION AND MELTING TEMPERATURES OF SILICATES<sup>1</sup>

Description	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Composition		MgO	BaO	MnO	Formation temp.	Fusion temp.
			FeO	CaO					
Iron slag <sup>2</sup> .....	50.0	17.0	3.0	30.0	.....	.....	.....	1392	1208
Iron slag <sup>2</sup> .....	43.9	8.6	4.5	31.4	10.2	.....	0.3	1450	1250
Lead slag <sup>2</sup> .....	36.0	8.5	40.0	4.0	3.0	7.5	.....	1220	1160
Lead slag <sup>2</sup> .....	31.47	.....	45.68	22.85	.....	.....	.....	1190	.....
Copper slag <sup>2</sup> .....	33.0	7.0	60.3	.....	.....	.....	.....	1273	1176
Copper slag <sup>2</sup> .....	40.80	.....	39.46	19.74	.....	.....	.....	1160	.....

<sup>1</sup> From HAVARD, "Furnaces and Refractories."

<sup>2</sup> See also pp. 697-705.

TOTAL HEAT IN CALORIES PER KG. OF MELTED SLAG  
(After AKERMAN)

Calories	Per cent., SiO <sub>2</sub>	Per cent., CaO	Per cent., Al <sub>2</sub> O <sub>3</sub>	Calories	Per cent., SiO <sub>2</sub>	Per cent., CaO	Per cent., Al <sub>2</sub> O <sub>3</sub>
347	59	36	5	360	31	37	32
	39	42	19		46	37	17
	63	35	2		58	32	10
	58	35	7		58	27	15
	58	37	5		62	37	1
350	53	37	10	380	38	52	10
	41	42	17		25	34	41
	38	47	15		44	33	23
	39	43	19		60	20	20
	37	40	23		65	35	0
	66	32	2	400	41	52	7
	59	38	3		37	53	10
	48	42	10		21	32	47
360	40	48	12		43	30	27
	34	48	18				

TYPICAL LEAD SLAGS<sup>1</sup>

	SiO <sub>2</sub>	Fe(Mn)O	Ca(Ba, Mg)O	Total
Eilers .....	28	50	12	90
Eilers . . . . .	30	40	20	90
Livingstone.. . . .	30	36	20	86
Iles. ....	32	33	23	88
Schneider .....	33	33	24	90
Page.....	33	36	16	85
Hahn .....	34	50	12	96
Raht.....	35	27	28	90
Hahn .....	36	40	20	96
Murray.....	40	34	26	100
Hixon.....	34	33	23	90
Hixon.....	33.4	34.1	21	88.5
Hixon.....	30	40	20	90

<sup>1</sup> HOFMAN, "Metallurgy of Lead," and HIXON'S "Lead Smelting and Copper Converting."

## MISCELLANEOUS FURNACE PRODUCTS

	SiO <sub>2</sub>	WO <sub>3</sub>	SnO	FeO	MnO Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	CaS	NaKO	P <sub>2</sub> O <sub>5</sub>	FeO
Iron blast furnace slag <sup>1</sup>	34.48		15.13	32.82	0.76	1.62	7.44	2.22	1.92	0.15	35.98
Acid open hearth slag <sup>1</sup>	48.19		12.30	49.39	3.56	15.74	0.09			14.78	9.10
Basic open hearth slag <sup>1</sup>	12.30		47.25	1.84		31.89	3.42				15.43
Bessemer converter slag <sup>1</sup>	47.25		3.45	50.76	1.00	2.05	4.00	1.71		21.90	4.73
Basic converter slag <sup>1</sup>	7.73		3.72	26.0		14.0			4.0		58.8
Charcoal iron furnace slag <sup>1</sup>	40.0		16.0	0.6					1.5		58.5
Arizona converter slag <sup>1</sup>	28.6		8.6	1.3					1.6		59.8
Arizona converter slag <sup>1</sup>	30.0		6.0						1.8		68.0
Arizona converter slag <sup>1</sup>	30.5		16.0						2.2		
Arizona converter slag <sup>1</sup>	21.4		9.6								
	SiO <sub>2</sub>	WO <sub>3</sub>	SnO	FeO	MnO Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	S	Cu	Total
Tin slag (glass), Cornish reverberatory <sup>1</sup>	39.4	1.3	8.1	26.2	Trace	7.9	0.5	1.7			99.9
Tin slag, French reverberatory <sup>1</sup>	40.0		7.5	20.3	11.1	9.6	3.6	1.0			93.1
Tin slag, Bohemia, from slag smelting <sup>1</sup>	24.06	24.03	9.36	20.75	5.64	9.00	3.5	0.37			
Tin slag, second slag smelting <sup>1</sup>	27.5	3.0	5.40	48.2	1.5	8.5	3.4	1.6			
Mansfield copper slag <sup>1</sup> (tr-silicate)	57.43	F-2.09		7.47		7.83	23.40	0.87		0.27	
Mansfield copper slag <sup>1</sup>	53.83			4.35		4.43	33.1	1.67		0.20	
Mansfield copper slag <sup>1</sup>	46.70			3.46	0.28	16.63	21.81	4.40	4.05	1.93	99.75
Ilsenburg copper slag (sp. gr. = 3.342) <sup>1</sup>	45.05			41.15		7.24	0.65	0.74		1.05	96.23
Oker (subsilicate) <sup>1</sup>	21.62			65.62		5.15	2.57			2.01	
Arizona copper practice <sup>1</sup>	35.6			31.9		22.3	9.6	0.7	2.08	0.35	

Arizona copper practice <sup>1</sup> .....	35.4					23.8		13.5	23.0	2.2				0.28
Arizona copper practice <sup>2</sup> .....	39.8					30.7		20.0	3.0	2.1				0.35
Arizona copper practice <sup>3</sup> .....	40.6					34.7		14.5	7.5					0.38
Arizona copper practice <sup>4</sup> .....	43.7					31.1		15.3	6.8	2.2				0.63
New Jersey cupola practice <sup>5</sup> .....	28.4					35.5			22.65					0.45
New Jersey matting furnace <sup>6</sup> .....	33.43					45.65								0.83 <sup>10</sup>
Arizona converter slag <sup>7</sup> .....	16.5					63.7		5.23	4.00	1.95				2.50
Blast-furnace sow <sup>8</sup> .....	2.14					Fe 7.82								86.98
Settler sow <sup>9</sup> .....	2.87					Fe 18.31								22.58
Copper converter slag, acid lining, Parrott <sup>2</sup> .....	36.80					Fe 50.40		6.80	tr.			4.43	0.47	1.00
Copper converter slag, acid lining, Anaconda <sup>3</sup> .....	35.70					Fe 55.83		0.22	1.76				1.03	2.14
Nickel slag, ore smelting <sup>11</sup> .....	38.0	Ni = 0.45				43.0		10.0	4.5	2.5			2.00	0.4
Nickel sow, ore smelting <sup>11</sup> .....	2.11	Ni = 4.85	Fe = 88.17										4.05	1.4
Zinc retort residue <sup>1</sup> .....	69.72					9.03		10.08	6.17	1.81	3.44	2.40	0.91	
Slag from basic lined refining furnace <sup>2</sup> .....	26.75													
Copper refinery slag.....	39.02					3.75			1.67	0.51				51.70
Lead slag from Freiberg <sup>4</sup> .....	27.2					10.54		4.19	5.04				0.61	35.2
Freiberg, lead slag, roasting and reduction <sup>4</sup> .....	23.95					40.0						10.1		
Pribram, lead slag, roasting and reduction <sup>1</sup> .....	37.50					44.41		0.92	4.45	4.75	0.54	P <sub>2</sub> O <sub>5</sub> 14.81	4.46	0.60
Lead blast furnace, Middle West, U. S. A. <sup>1</sup> .....	30.67					28.37		2.51	7.81	14.70	1.11	2.11	4.07	0.92
Lead Reverberatory, Middle West, U. S. A. <sup>3</sup> .....	41.35					30.40			15.50	10.95	6.02		1.09	0.22
						1.00			27.05	17.50	3.14			

<sup>1</sup> HENRY LOUIS, "Tn."<sup>2</sup> SCHNABEL's "Handbook of Metallurgy"<sup>3</sup> Private notes. Some of these Arizona slags are interesting because of their high alumina content.<sup>4</sup> Private notes. A wonderfully clean slag, almost snow white in color.<sup>5</sup> Private notes. <sup>6</sup> Poured slag, quartz lining.<sup>7</sup> Poured slag, ore lining.<sup>8</sup> This nickel slag, given by SCHNABEL, is far from typical of modern operations.<sup>9</sup> Practice gave the following average for the blast-furnace slag: SiO<sub>2</sub>, 35.37; Fe, 34.69; CaO, 5; MgO, 5.10; Al<sub>2</sub>O<sub>3</sub>, 8; S, 0.82; Cu, 2.4; Ni, 3.9 per cent. The corresponding matte, for a yearly average, carried: Ni, 19.33; Cu, 13.23 per cent. The succeeding year gave: SiO<sub>2</sub>, 34.89; Fe, 38.06; S, 1.01; Cu, 2.9; Ni, 3.9; with corresponding matte: Ni, 20.55; Cu, 10.7 per cent. The year following this showed: SiO<sub>2</sub>, 33.90; Fe, 39.59; S, 1.31; Cu, 1.8; Ni, 3.9; with corresponding matte: Ni, 20.92, and Cu, 8.57 per cent.<sup>10</sup> 60 per cent. matte being produced.<sup>11</sup> Private notes. For instance, a year's results in Canadian

TYPICAL FURNACE PRODUCTS

	Cu	Pb	Fe	Ni	Co	Sb	As	Ag	Au	S	Bi	Zn
Speiss—Schmöltnitz <sup>1</sup> .....	12.99	0.09	12.63	1.40	0.09	60.00	7.42	0.36	0.06	2.04	1.26	.....
Speiss—Neuschlitz.....	41.18	0.69	35.41	0.09	0.04	10.79	6.10	0.03	.....	2.60	.....	.....
Black copper—Mansfeld.....	94.52	1.93	0.62	0.76	0.23	.....	.....	0.03	.....	0.86	.....	.....
Converter copper—Mexican.....	95.64	1.864	0.068	.....	.....	0.171	0.085	1.63	0.002	.....	None	1.09
Converter copper—Australian.....	96.39	0.684	0.0123	.....	.....	0.364	0.509	0.33	0.041	0.265	0.088	.....
Converter copper—Australian.....	.....	0.262	0.116	0.100	.....	0.012	tr.	0.30	0.01	0.242	.....	.....
Converter copper—Western U. S.....	99.28	*tr.	0.044	0.014	.....	0.010	0.016	0.34	0.01	0.005	0.004	.....
Lead from blast furnace—Freiberg <sup>1</sup> .....	0.225	95.088	0.007	.....	.....	0.958	.....	0.47	.....	.....	0.019	0.002
Lead from Freiberg <sup>1</sup> .....	0.11	97.359	0.003	0.001	.....	1.524	.....	0.423	.....	0.03	0.007	0.001

<sup>1</sup> SCHNABEL, "Handbook of Metallurgy."An average representing 44 per cent. of the slag produced in the 1917 pig-iron production of the United States was: CaO, 40.17; Al<sub>2</sub>O<sub>3</sub>, 13.07; SiO<sub>2</sub>, 35.52; MgO, 5.51; CaS, 3.87; unaccounted for, 2.06 per cent.

**Matte Smelting<sup>1</sup>**

In order of decreasing affinity for sulphur<sup>2</sup> the chief metals stand thus according to

FOURNET: Cu, Fe, CoNi, Sn, Zn, Pb, Ag, Hg, Au, As, Sb.<sup>2</sup>

SHÜTZ: Mn, Cu, Ni, Fe, Sn, Zn, Pb.<sup>2</sup>

**Specific Gravities of Matte-forming Compounds<sup>3</sup>**

Substances having a specific gravity not greater than 4.7: the sulphides of zinc, molybdenum, calcium and manganese.

Substances having a specific gravity between 4.7 and 5.5: the sulphides of barium, iron, cadmium, nickel, cobalt, and copper; and the magnetic oxide of iron.

Substances with specific gravities from 6 to 9: the sulphides of silver, lead and bismuth; the arsenides and antimonides; and the sulpharsenides and sulphantimonides of silver, copper, bismuth, lead, iron, cobalt and nickel; and metallic lead, iron and copper.

**Temperatures of Metallurgical Operations****Copper blast-furnace smelting:**

Furnace running fast. . . . .	1260°C. <sup>1</sup>
Normal smelting . . . . .	1215°C. <sup>1</sup>
Slow smelting, lower limit. . . . .	1130°C. <sup>1</sup>
Pyritic smelting. . . . .	1240°-1350°C. <sup>1</sup>

**Copper converters:**

Matte introduced. . . . .	1170°C.
Turned down to skim. . . . .	1297°C.
Turned back to blow. . . . .	1284°C.
Cooling during skimming. . . . .	13°C.
Temperature of escaping gas at end of 10 minutes	1260°C.
Temperature of escaping gas at end of 20 minutes	1270°C.
Temperature of escaping gas at end of 30 minutes	1275°C.
Temperature of escaping gas at finish . . . . .	1195°C.

**Copper-refining furnaces:**

Charge melted and ready to rabble . . . . .	1141°C.
After 25 minutes rabbling. . . . .	1103°C.
After 75 minutes rabbling. . . . .	1103°C.
At end of rabbling. . . . .	1103°C.
After 20 minutes poling . . . . .	1110°C.
At end of poling. . . . .	1117°C.
Heated to. . . . .	1125°C.
After ladling 20 minutes. . . . .	1121°C.

<sup>1</sup> HOFMAN'S "General Metallurgy," p. 74

<sup>2</sup> But in a wet way SCHÜRMANN places the sulphides in the following order as regards the rate at which they are decomposed by the nitrates, sulphates and chlorides of other metals: Pd, Hg, Ag, Cu, Bi, Cd, Sb, Sn, Pb, Zn, Ni, Co, Fe, As, Ti, Mn. Thus PdS is not decomposed by the salts of any of the other metals, while PdCl<sub>2</sub> converts the sulphides of the other metals into chlorides. With MnS, this is decomposed by salts of any of the other metals, while MnSO<sub>4</sub> has no decomposing effect.

<sup>3</sup> HOFMAN'S "General Metallurgy," p. 74.

**Lead blast-furnace work:**

On two-fifths slag, Fe, 30 per cent.; CaO, 12 per cent.;  $\text{Al}_2\text{O}_3$ , 8 per cent.;  $\text{SiO}_2$ , 31 per cent., Zn, 10 per cent.; was  $1126^\circ\text{C}$ .

On half slag,  $1134^\circ\text{C}$ .

On three-fifths slag, Fe, 30.5 — 31 per cent.; CaO, 15 — 14.5 per cent.;  $\text{Al}_2\text{O}_3$ , 6.4 — 6.6 per cent.;  $\text{SiO}_2$ , 34 — 32 per cent.; Zn, 5.8 per cent.;  $\text{MgO}$ , 1.3 per cent., MnO, 3.7 — 3.8 per cent.,  $1170^\circ - 1149^\circ\text{C}$ .

The temperature change seems to be about  $9^\circ\text{C}$ . per cent. of silica up or down, from the above figures.

**Reverberatory smelting—copper matting:**

Slag temperature.....  $1200^\circ - 1310^\circ\text{C}$ .<sup>1</sup>

Slag melting point.....  $1190^\circ - 1285^\circ\text{C}$ .<sup>1</sup>

Furnace temperatures.....  $1260^\circ - 1725^\circ\text{C}$ .<sup>1</sup>

**Reverberatory roasting—lead matte:**

$1215^\circ\text{C}$ . at fire box to  $505^\circ\text{C}$ . at flue end.

**Reverberatory smelting flue:**

$1300^\circ\text{C}$ . at furnace;  $1217^\circ$  at 14 ft. from furnace;  $1112^\circ$  at 27 ft.;  $1097^\circ$  at 41 ft.;  $1045^\circ$  at 54 ft.;  $911^\circ$  at 67 ft.;  $807^\circ$  at 80 ft.;  $767^\circ$  at 94 ft.;  $727^\circ$  at 107 ft.;  $642^\circ$  at 120 ft. (foot of stack).

**IRON<sup>2</sup>**

	Deg. C.
Blast furnace at tuyères.....	2000
Blast-furnace tapping.....	1600
Open-hearth furnace from $1566^\circ$ at rever-	
sals to $1725^\circ\text{C}$ . max.	
Medium-hard steel at tapping ..	1530
Gas leaving producers.....	700
Gas leaving regenerators.....	1200
Air leaving regenerators.....	1100
Waste gas at stack ..	300
Medium steel ready to roll ..	1050
Glass pots working.....	1050
Glass pots refining ..	1325
Tanks for casting glass.....	1325
Crucible-steel furnace.....	1300
Cement rotary clinkering kiln..	1684
Ingot being rolled ..	1065
Heating furnace.....	1150
Basic bessemer lining, above charge	1350 to 1550

<sup>1</sup> Rounded averages (to nearest  $5^\circ\text{C}$ ) of figures given by G. H. CLEVENGER *Metallurgical and Chemical Engineering*, August, 1913. Other figures not averaged

<sup>2</sup> STOWE-FULLER Co.'s catalog.



MODERN COPPER BLAST FURNACES<sup>1</sup>

	Dimensions at tuyère, in	Number and size of tuyères, in	Center of tuyère to feed floor ft in	Height of smelting column, ft.	Blast pressure, oz.	Approximate capacity, tone per day
Anaconda, Mont <sup>2</sup>	56 × 1044	150-4	19		40	3000
Cananea, Mexico	48 × 210	30-4 3/4	10 4 1/2	9	16	280
Garfield, Utah	48 × 240		13 0	10	24	360
Mammoth, Calif	50 × 180	34-4 3/4		9	42	400
Steptoe, Nev	42 × 240	48-4			40	300-500
Cerro de Pasco, Peru	56 × 180	28-4			24	300
Mason Valley, Nev.	47 × 300	50-4	12 1	12	42	720
Tezuitlan, Mex	54 × 240	40-5	14 6		28-32	500
Canadian	50 × 204			14		400
Copper Co.	50 × 240			14		550
Mond Nickel Co	50 × 240			12		550
Trail, B. C.	42 × 210			8		350
	42 × 360			8		650
	42 × 264			8		460
	42 × 420			8		700
	50 × 420			8		875
Grand Forks, B. C.	44 × 266 1/2			12		500
	48 × 260			12		550
Great Falls, Mont	84 × 180		22 3 1/2			
Kosuka, Japan	48 × 294	32-6		9	16	160
United Verde Ariz	48 × 330					
Anoxy, B. C.	50 × 360			12		750
B. C. Copper Co.,						
B. C.	51 × 360	72-3 1/2	5 3	12		850
	51 × 240	72-3 1/4	5 3	12		550
Tyce copper, B. C.	42 × 120			6		200
	48 × 160			6		300

<sup>1</sup> From GOWLAND'S "Metallurgy of the Non-ferrous Metals," p 83, and Bull 209, Canad Dept of Mines

<sup>2</sup> The Anaconda furnace is the largest yet constructed

## Blower Capacity

Iron Cupola Work.—500 cu. ft. of air per minute is required to melt 1 ton of pig iron per hour.<sup>1</sup>

Rotary blowers seem to require 5 hp. for every 1000 cu. ft. of air discharged at 1 lb. pressure.<sup>2</sup>

Copper Blast Furnaces.—At the Tennessee Copper Co. 1000 cu. ft. per minute per linear foot of furnace is the rule (56 × 270-in. furnace). At Mt. Lyell 20,000 cu. ft. at 64 oz. pressure is used per minute in a 54 × 210-in. furnace. At Great Falls, Mont., a furnace 84 × 180 in. at the tuyères receives 17,000 cu. ft. of air per minute. The Sasco, Ariz., smeltery used 13,000 cu. ft. per minute at 24 oz. pressure for a 43 × 192-in. furnace. Cananea used 12,000 cu. ft. per minute at 16 oz. pressure for a 48 × 210-in. furnace.

Lead Blast Furnaces.—The modern tendency is toward higher pressure. Tooele is using 44 oz. (1929). At Murray,

<sup>1</sup> HOFMAN, "General Metallurgy," p 777

<sup>2</sup> *Ibid.*, p 771

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Utah, the pressures have been allowed to go as high as 70 oz. Midvale limits it to 52 oz. per sq. in.

Converters.—The Copper Queen works figures that it requires 85,000 cu. ft. of blast to convert 1 ton of matte to blister copper. See also p. 725.

### Operations at the British Columbia Copper Co.'s Smelter<sup>1</sup>

**Blast Furnaces.**—The blast furnace building is 150 ft. long by 160 ft. wide and contains three water-jacketed blast furnaces placed end to end, with space between them for the minor axis of a 10 by 18-ft. oval settler. The two outside furnaces, Nos. 1 and 3, are each 51 by 360 in., while the middle one, or No. 2, is 51 by 240 in. in area at the tuyères. The vertical distance from the center of tuyères to the feed floor is 16 ft., and to the sole plate 37 in., the other furnace dimensions being as follows:

	30-ft. Furnace	20-ft. Furnace
Hearth area, sq. ft. . . . .	127.5	85
Center tuyères to tapping floor. . . . .	5 ft. 3 in.	5 ft. 3 in.
Height of bottom jackets. . . . .	9 ft. 0 in.	9 ft. 3 in.
Width of side jackets. . . . .	3 ft. 4 in.	3 ft. 4 in.
Width of end jackets, bottom . . . . .	3 ft. 8 in.	3 ft. 8 in.
Width of end jackets, bottom . . . . .	6 ft. 2 in.	6 ft. 2 in.
Number of tuyères. . . . .	72	48
Diameter of tuyères. . . . .	4 in. bushd to 3¼ in.	
Area of tuyères. . . . .	597.4 sq. in.	602.9 sq. in.
Tuyère area per square foot of hearth area. . . . .	4 65 sq. in.	7 09 sq. in.
Center line to center line tuyères . . . . .	9 25 in.	9.25 in.
Water space in jacket, 4 in.; plate used on inside ⅝ in.; on outside, ⅜ in.		

### A Résumé of Furnace Operating Data, B. C. Copper Co.

Tons smelted per day, 2250.0; tons smelted per square foot of hearth area, average, 6.62; tons smelted per square foot of hearth area, maximum, 8.70; tons smelted per man per day, 35.70; Cu on charge, per cent., 0.8 to 1.2; Cu in matte, per cent., 30.0 to 45.0; Cu in slag, per cent., 0.22 to 0.27; S on charge, per cent., 2.00; S burnt off, per cent., 85.00 to 90.00; coke used on charge, per cent., 12.00 to 14.00; coke ash, per cent., 20.00 to 28.00; blast, cubic feet per minute, 25,000; blast temperature, atmospheric; cooling water for jackets, gallons per minute, 2500; men per 8-hour shift, 21.0; matte, per cent. of total charge, 1.65; matte, specific gravity, 5 to 0; slag, per cent., SiO<sub>2</sub>, 38 to 45; Fe, 13 to 20; CaO, 20 to 26; Al<sub>2</sub>O<sub>3</sub>, 6 to 9; specific gravity, 3 to 3.2.

<sup>1</sup> From a paper by F. K. BRUNTON, *Trans. A.I.M.E.*, 1915.

JACKET WATER REQUIRED<sup>1</sup>

Hearth area, square feet	Water per hour, blowing in or out, gallons	Water per hour, normal running, gallons
3	900	460
5	1200	600
7	1450	950
9.5	2200	1100
12.5	3000	1300
18	4000	1500
24	5000	1800
30	6000	2000
36	7000	2200

<sup>1</sup> PETERS' "Modern Copper Smelting."

## ANALYSIS OF COPPER BLAST FURNACE GASES

	O	CO	CO <sub>2</sub>	SO <sub>2</sub>	SO <sub>3</sub>	N
Morenci, Ariz. . .	8.0	2 15	10.9	2.5	.....	.....
Globe, Ariz. . . .	17.2	3.2	...	3.5	.....	.....
Copper Queen. . .	10.0	(H <sub>2</sub> O 3.5)	6.49	1.27	0.086	78.1
Tennessee <sup>1</sup> . . . .	.....	.....	3 5	3.50	Tr.	.....

<sup>1</sup> As delivered to sulphuric acid chambers. According to ROBERT STICHT'S data, all of the above results showing free oxygen are open to doubt, as he believes that oxygen can only be present in the free state in copper furnace gases when extraneous air is drawn into the testing apparatus via the charge doors.

Coal-dust Firing of Reverberatories<sup>1</sup>

A general discussion by C. J. GADD of the principles of coal-dust firing appears in the *Journal* of the Franklin Institute for 1916, p. 323. The main points are as follows: Powdered coal, used as a fuel in metallurgical furnaces, should be high in volatile matter and low in ash, and should not contain over 0.75 per cent. H<sub>2</sub>O. At least 95 per cent. of the coal should pass through a sieve with 100 meshes to the linear inch, and over 83 per cent. through a 200-mesh sieve; it must be delivered to the furnace "in a thoroughly atomized state," and combustion must be completed while the coal is in suspension. Delivery to the furnace must be uniformly controlled, and the personal equation reduced to a minimum. While anthracite, lignite and coke breeze may be used, the most desirable fuel is bituminous coal, high in volatile matter and low in S and ash. The coarse coal should approximate the following analyses:

<sup>1</sup> Bull. A.I. M.E., January, 1915.

	For heating and puddling furnaces, per cent.	For open- hearth furnaces, per cent.
Volatile matter not under.....	30.00	36.00
Fixed C not under.....	50.00	52.00
H <sub>2</sub> O not over.....	1.25	1.25
Ash not over .....	9.50	6.00
S not over.....	1.00	1.00

Powdered coal should be handled in bulk; aerial propulsion and transfer in the form of dust clouds should be avoided on account of the danger of accidental ignition. Powdered coal, stored for any length of time, tends to fire, pack, and collect moisture. Spontaneous combustion invariably occurs within 6 days with a moisture content of approximately 0.75 per cent. and a S content of 1.0 per cent., and may occur within 24 hours if the H<sub>2</sub>O content exceeds 1.0 per cent., and the S content be 4 to 5 per cent. The apparatus for crushing, drying, pulverizing, feeding, and burning the coal is described in detail, as are various types of metallurgical furnaces equipped for burning powdered coal. A low pressure burner gives a short flame, a high pressure burner a long flame. Powdered coal is more economical than oil or producer gas. The temperature is as high as that given by producer gas, and is maintained uniformly throughout the furnace. The high fuel consumption is offset by the generation of steam in the waste-heat plant, where each pound of coal, burned in the furnace, evaporates approximately 6.25 lb. of steam.

Experiments were made with this process at the plant of the Canadian Copper Co. at an early date, but were unsuccessful for some time.

It was finally adopted at Copper Cliff, however, designing furnaces especially to meet the requirements by eliminating right-angled bends in the flues and placing the skimming door at the side instead of the end. The waste-heat boiler was made a secondary consideration. The first smelting showed no difficulty with the fuel, and as improvements were gradually made the smelting became more efficient. In the first 3 months of 1914 the fuel ratio was 5, 5.65 and 6.77, respectively. The method of feeding has been changed. At first it was done through hoppers near the fire end, but is now done almost entirely through pipes in the side walls. Coal dust is introduced through five pipes 5 in. in diameter. It is first dried and then ground so that about 95 per cent. passes a 100-mesh and 80 per cent. passes a 200-mesh screen. The great advantage found in this method of firing is the absence of breaks in the temperature curve due to grating or cleaning the hearth, and as a consequence a greatly increased tonnage and fuel ratio.

At Anaconda coal-dust firing was tried in June, 1914, in a furnace 124 ft. by 21 ft. The method of charging was similar to that used at Copper Cliff. From the experience gained in this work, Mr. BENDER lays down the following requisites for

successful use of coal dust: (1) The coal should be dried before pulverizing, containing not more than 1 per cent. moisture; (2) fine pulverization affords increased area and higher thermal efficiency, 95 per cent. should pass a 100-mesh screen and 85 per cent. a 200-mesh; (3) the quantities of coal and air delivered to the furnace should be carefully controlled in order to secure complete combustion; (4) the coal should contain enough volatile combustible matter to give the required combustion; a standard for cement work is 30 per cent.; (5) the furnace should be properly designed and equipped, and (6) provision must be made for taking care of the ash. Based on past experience, some changes will be made in the new equipment for coal-dust reverberatory firing at Anaconda. The furnaces will be 144 ft. by 25 ft., with a flue area of 48 sq. ft. Matte will be tapped at the front. The skimming plate will be 12 in. higher than in other furnaces, the top of the plate being 24 in. above the tap hole. Recent records for a week at Anaconda indicate the efficiency of coal-dust firing; the average tonnage per day was 542.7, with a fuel ratio of 7.5.

**Coal-dust Firing at Anaconda.**—The ore-smelting reverberatories at Anaconda are  $23\frac{1}{3} \times 133$  ft., the latest furnaces being completely jacketed. The coal is ground so that 96 per cent. will pass 100 mesh, and 74 per cent. will pass 200 mesh. The equipment consists of two  $30 \times 30$  Jeffries single-roll crushers; three Ruggles-Coles driers; twelve  $4\frac{1}{2}$ -ft. Raymond pulverizers. Warford burners are used, with primary air at 16-oz. pressure.

**Refining Furnaces.**—The copper refinery at Great Falls is equipped with two furnaces having hearths 45 ft. long. One of these furnaces has a hearth 13 ft. 9 in. wide; the other is 18 in. wider. These furnaces have silica-brick bottoms, 32 in. thick, arranged for air cooling. Each furnace is equipped with a Stirling waste-heat boiler generating about 4,000 b.hp. The furnace stacks are 5 ft. in diameter and 142 ft. in height, measured from the working-floor level. No trouble was experienced from lack of draft.

When the change was made from grate firing to pulverized coal, the coal hoppers directly over the furnace fireboxes were used as storage for pulverized coal.

Except for the removal of the fireboxes, no changes were made in the furnace design when the change was made from grate firing to coal dust firing.

**Effect of Pulverized Coal on Furnace Operations.**—An operator considering a change from grate firing to pulverized coal is desirous of knowing what economies may be brought about by the change. The use of pulverized coal at Great Falls enabled us to make our cycle with reasonable certainty every 24 hr. We were even able to make such minor repairs to flues and jambs as did not necessitate a shutdown and still take out seven charges weekly. A loss of 1 or 2 hr. on one day caused by such a repair could be caught up and the furnace brought around on schedule again within a day or two, at the most, and without any material sacrifice of production.

The saving in time, as compared with grate-firing, is brought about first, by the saving of time required in grating and removing clinkers from the firebox; second, by reason of the fact that when we were ready to start charging, the burners could be adjusted so as to maintain the heat in the smelting chamber to a much greater extent than is possible when grate-firing; third, during the melting period, conditions of combustion were far more uniform than was previously the case. Not only did this lead to a shorter melting period, but, due to the ability to maintain an oxidizing atmosphere in the furnace at all times while melting down, the rabbling period was materially shortened.

The use of pulverized coal also resulted in a considerable saving in fuel cost. The best fuel ratio we were able to maintain for an entire month, using coal with grate firing, was 4 tons of copper per ton of coal. With the same quality of coal used in the pulverized form, we obtained a ratio of 6.8 tons of copper per ton of coal over a 6 months' period. This represents a saving of 41 per cent. in the coal bill, assuming that the cost of pulverizing is offset by a reduction in labor at the furnace and elimination of the cost of handling and disposing of ashes. A further saving was, however, realized for when burning coal on grates, lump coal only could be used; whereas when the coal was used in the pulverized form, slack coal, costing 20 per cent. less could be used. The net result was a reduction of from 40 to 50 per cent. in the fuel cost per ton of copper.

Regarding the use of powdered coal as a fuel for copper-refining furnaces, E. S. BARDWELL, *Trans. A.I.M.E.*, 1925, says that no trouble need be anticipated from sulphur if the coal runs under 2 per cent. S. The ash should be less than 8 per cent.

**Pulverizing Coal.**—At the plant of the Nevada Consolidated Copper Co. the average power consumption was 30 kw.-hr. per ton of coal pulverized (*Trans. A.I.M.E.*, February, 1920).

### Reverberatory Practice

Some of the essentials of good ore-smelting reverberatory practice are thus summed up by R. E. H. POMEROY.<sup>1</sup>

1. Careful preparation of the charge by adequate mixing of all ingredients before charging.

2. Addition of enough lime rock, preferably coarse, to produce an active boiling in the furnace.

3. Maintaining a deep bath of molten matte to equalize and distribute the heat over the whole of the hearth.

4. Frequent skimming so as to carry only a thin layer of slag over the matte bath.

5. Operating the furnace for the best smelting conditions, ignoring the waste-heat boilers as factors in the power supply.

Factors affecting the life of the furnace:

1. The furnace roof set high over the hottest portion of the hearth.

2. Frequent fettling to protect the side walls.

<sup>1</sup> *Bull. A.I.M.E.*, February, 1915.

3. Frequent charging and active charge mixtures to avoid floater and blanket formation requiring excessive firing.

The largest copper-ore-smelting reverberatory, so far as known, is the new one at Anaconda, with a 23 ft. 4 in.  $\times$  134 ft. 6 in. hearth. A furnace 178 ft. long has been built for settling reverberatory slags. The largest copper-refining reverberatory is, so far as known, 14  $\times$  45 ft., and has cast a charge of 750,000. lb. These figures are due to the courtesy of FRANCIS R. PYNE.

### Converters at Anaconda

The present basic-lined converters at Anaconda take a 70-ton matte charge and 15 tons of ore (60 per cent.  $\text{SiO}_2$ ); 10 per cent.  $\text{Al}_2\text{O}_3$ . Air having a pressure of 16 lb. per sq. in. is used and the converters are electrically operated. The slag is sent while hot to a reverberatory furnace 21  $\times$  153 ft., which treats 650 tons of slag and 450 tons of fluxes per day, burning 85 tons of coal. The gases from this furnace pass to a flue 15 ft. wide by 13 ft. high divided into two parts leading to two 850 hp. Stirling waste heat boilers. Either or both boilers may be used.

**Converter Slag Treatment.**—The rise of flotation methods has produced an excess of iron rather than an excess of silica to be cared for by the copper smelter, with the result that copper converter slags are no longer desirable as a flux.

Anaconda in 1918 met this problem by sending all converter slags to one reverberatory furnace in which the  $\text{Fe}_3\text{O}_4$  of the converter slag was reduced to  $\text{FeO}$ , the  $\text{FeO}$  fluxed to a slag containing about 30 per cent.  $\text{SiO}_2$ , and the copper and white metal reduced to a low grade matte by the use of unroasted or underroasted concentrates and fine siliceous ore (F. LAIST and H. J. MAGUIRE, *Trans. A.I.M.E.*, January, 1920).

The furnace, from burners to skimming block was 23 ft. 4 in. by 153 ft., with an 8 ft. 6 in.  $\times$  6 ft. flue connection. The flue was split, with an 865 hp. waste heat boiler in each flue. The furnace was equipped with hoppers on both sides for the full length of the furnace and in the center for 100 ft. from the burners. Firing was by five pulverized coal burners, using 16-oz. air.

The converter slag was charged by pouring into a cast-iron launder on wheels and provided with a replaceable lip. Two of the center hoppers have 10-in. openings so chilled slag or cleanings can be charged.

The slag from the furnace carried about 30–33 per cent  $\text{SiO}_2$ ; 49–51 per cent.  $\text{FeO}$ ; 0.9–2.5 per cent.  $\text{CaO}$  and about 0.55 per cent.  $\text{Cu}$ , producing a matte running from 36–52 per cent.  $\text{Cu}$ .

Direct cost of treating the slag is about 47 cts. per ton. Crediting steam at \$9 per boiler horsepower per month, the cost is about 35 cts. per ton.

**Converter Blast.**—According to STICHT, about 100,000 cu. ft. of air is required per long ton of copper produced from 50 per cent. matte and 165,000 cu. ft. of air for a long ton of copper

from 40 per cent. matte. At one American works 183,000 cu. ft. of air is required per 2000 lb. of Cu produced.

**Lining.**—About 2 tons of copper will be produced per ton of lining in the acid converter.

**Gases.**—The following analysis of gas passing through a converter flue is given by DUNN (*Trans. A.I.M.E.*, 1913): SO<sub>2</sub>, 2.845 per cent.; SO<sub>3</sub>, 0.0515; CO<sub>2</sub>, 0.2084; H<sub>2</sub>O, 1.061; As<sub>2</sub>O<sub>3</sub>, 0.00073; O, 12.04; N, 83.64 per cent.

### Sulphuric-acid Manufacture

As the regions surrounding smelteries grow more densely populated, the difficulties caused by the discharge of sulphuric acid and sulphur dioxide into the atmosphere and the probability of being forced into sulphuric-acid manufacture increase. The contact-acid process does not seem successful for smelting plants, probably because of the arsenic in the fumes poisoning the catalyst, although the new vanadium catalysts of the Selden process seem for less subject to poisoning than do the older platinum catalysts, in addition to their being cheaper. In the chamber process one has the ordinary chambers, the Meyer tangential system, the Falding highchamber, and the still experimental lead spirals to choose from. The Falding system as adopted at the Tennessee Copper Co. was described by its inventor in the Eng. and Min. Journ. of Sept. 4, 1909, p. 443. In that article he makes the following comparison between the systems:

	Chamber space, cu. ft.	Ground area, sq. ft.	Weight of lining, tons
Old System.....	174,960	12,936	112
Meyer tangential. .	174,480"	11,938	110
Falding	175,000	4,096	66.5

Acid manufacture at the Ducktown Sulphur, Copper & Iron Co.'s plant was described in the Journal of May 28, 1910, by W. H. FREELAND and C. W. RENWICK. That plant was designed for a capacity of 160 tons of 60° B. acid per day. Under normal conditions the gases delivered to the chambers analyze: SO<sub>2</sub>, 3½ per cent.; CO<sub>2</sub>, 3½ per cent.; and SO<sub>3</sub> trace. Temperature control of the gases is attained by small kite-shaped flues through varying lengths of which the gases can be run, until they are sufficiently cool. There are two Glover's towers, each 12 ft. square and 45 ft. high. Following these are four hard-lead fans (10 per cent. antimony) then two sets of eight chambers each. Each chamber is 96 ft. long, 22 ft. 8 in. wide and 30 ft. high. Special arrangements are said to be introduced here to take care of the carbon dioxide in the gases.

<sup>1</sup> The matter of the ill effect of carbon dioxide in chamber work is by no means settled. Lunge says one Bohemian works with which he was acquainted made acid without trouble or special precautions from material carrying 10 per cent. of bituminous matter.



Six Gay-Lussac towers are used for recovery of the nitrous acid.

In a discussion of pyritic smelting and acid manufacture by Falding and Channing (*Eng. and Min. Journ.*, Sept. 17, 1910) the necessity of a uniform composition of gas is insisted upon by these authors, and the general point made that an acid plant drawing its gases from several furnaces will more probably be successful than if it draws its gas from one.<sup>1</sup>

The Anaconda Copper Co. in 1915 constructed a 100-ton acid plant, but this was as an adjunct to a leaching plant, and not to use blast-furnace gases. It was described by E. L. LARISON in the *Eng. and Min. Journ.* of Aug. 24, 1929.

There are three units, two chamber units of 135 tons and 50 tons 60° acid daily capacity, and a packed cell unit of 20 tons 60° daily capacity. Sulphur dioxide to supply these plants is drawn from three WEDGE roasters treating copper concentrate from WILFLEY tables carrying 40 per cent. S and 9 per cent. Cu. The gas carries 7 to 8 per cent. SO<sub>2</sub>.

The large chamber unit consists of a Glover tower, eight large rectangular lead chambers and three Gay-Lussac towers. The smaller unit consists of a Glover tower, eight rectangular lead chambers and two Gay-Lussac towers.

The packed-cell unit consists of a Glover tower, five brick-packed reaction towers, and two Gay-Lussac towers. The heat of reaction is removed by circulating 50° acid through the towers and cooling it in coil-type acid coolers. The plant uses only about 1 cu. ft. of packed volume per pound of sulphur converted per 24 hr., against about 18 cu. ft. chamber space.

In Europe, the Schmiedel process seems to be gaining ground, as least as an adjunct to blende-roasting plants. In this the sulphur-bearing gases are beaten up with nitrated acid by means of fluted rollers. Acid of 78 per cent H<sub>2</sub>SO<sub>4</sub> strength is said to be produced by this mechanical means. A Schmiedel box is about 7m. long × 1 m. square.

### Miscellaneous Data for Lead Metallurgy<sup>2</sup>

#### ZINC REQUIRED FOR DESILVERIZING LEAD

Silver in lead, per cent	Zinc required, per cent	Silver in lead, per cent.	Zinc required, per cent.
0.025	1.25 (a)	0.3	2.00 (a)
0.05	1.33 (a)	0.38	1.84 (b)
0.1	1.5 (a)	0.51	1.96 (b)
0.15	1.66 (a)	0.84	2.45 (b)

(a) According to ILLING. (b) According to JUNE

NOTE.—At 350°C lead dissolves 0.6 per cent of Zn; at 650° it will dissolve 3.0 per cent of Zn.

<sup>1</sup> In plants making sulphuric acid from pyrites, the inlet gases are considered to be best at 8.8 per cent SO<sub>2</sub>, 9.6 per cent O<sub>2</sub>; when burning briquet stone, the gases should contain 10.65 per cent SO<sub>2</sub>, 10.35 per cent O<sub>2</sub>.

<sup>2</sup> SCHNABEL'S "Handbook of Metallurgy" The Macmillan Co.

## TYPICAL MATTES FROM LEAD SMELTING

	Speiss, Leadville	Speiss, St. An- dreasberg	Matte, Pueblo	Matte, Pueblo	Raw matte, Clausthal	Roasted matte, Clausthal
Ag..	0.0085	.....	.....	.....	0.0299	0.0327
Au...	tr.	.....	.....	.....	.....	.....
Cu..	0.3628	18.37	20.40	10.35	4.620	4.123
Pb..	1.4935	66.84	8.50	12.45	10.665	10.492
Mo..	0.2110	.....	.....	.....	.....	.....
Fe...	60.578	0.22	41.20	42.50	53.112	52.411
Zn...	tr.	0.04	1.50	3.10	2.110	2.459
Ni...	0.0876	} 0.13	.....	.....	0.312	0.350
Co..	.....		.....	.....	.....	.....
S...	5.1891	.....	26.30	26.40	.....	.....
As..	31.4725	tr.	tr.	0.12	26.877	0.613
Sb..	tr.	3.60	tr.	0.05	0.267	0.128
SiO <sub>2</sub> .	.....	.....	0.20	0.30	0.510	1.486
CaO.	.....	.....	.....	0.15	0.383	0.336
Sn...	.....	10.60	0.16	0.21	.....	.....
Bi...	.....	tr.	.....	.....	.....	.....
Mn..	.....	.....	1.40	3.30	0.385	0.317
O.....	.....	.....	.....	.....	.....	22.966
SO <sub>2</sub> ..	.....	.....	.....	.....	.....	4.225

Effect of Steam on Molten Lead<sup>1</sup>

If the temperature of the lead be below the melting point of zinc, steam will bring to the surface a zinc crust with some of the silver.

If the temperature of the lead be slightly above the melting point of zinc, the steam will cause a thorough mixing of the zinc and lead.

If the temperature be between a dark red and an incipient cherry red, the steam will cause a scum to rise, containing about 3 per cent. of zinc, which does not, however, take any silver away from the lead.

If it be a clear cherry red, the zinc will decompose the steam; the zinc oxide, mixed with lead oxide, collects as a powder on the surface of the lead.

<sup>1</sup> HOFMAN'S "Metallurgy of Lead."

SOFTENING LEAD<sup>1</sup>

	Clausthal		Lautenthal		Freiberg		Denver	
	Before dressing	After dressing	Before dressing	After dressing	Before dressing	Liquated dross (5%)	Dross before liquating	Dross after liquating
Pb	98.92944	99.0239	98.96475	99.1883	96.667	62.40	53.0	50.0
Cu	0.1862	0.1096	0.2838	0.0907	0.940	17.97	18.2	26.8
Cd	Tr.	None	Tr.	None	.....	.....	.....	.....
Bi	0.0048	0.0050	0.0082	0.0083	0.066	None	.....	Au = 0.30 oz.
Ag	0.1412	0.1420	0.1430	0.1440	0.544	0.17	..	75.00s.
As	0.0064	0.0053	0.0074	0.0032	0.449	2.32	...	7.31
Sb	0.7203	0.7066	0.5743	0.5554	0.820	0.98	...	0.18
Sn	None	None	None	None	0.210	0.04	.....	.....
Fe	0.0064	0.0042	0.0089	0.0048	0.027	0.43	.....	.....
Zn	0.0028	0.0017	0.0024	0.0015	0.022	0.07	.....	.....
Ni	0.0023	0.0017	0.0068	0.0038	0.0055	1.09	..	..
Co	0.00016	Tr.	0.00035	Tr.				
S	.....	.....	.....	.....	0.200	4.00	2 0	3.6
O	.....	.....	.....	.....	.....	1.87	.....	.....
Slag,	ash, hear	th mate	rial.....	.....	.....	8.66	1.8	4 8

<sup>1</sup> HOFMAN'S "Metallurgy of Lead."

## PATTINSON'S PROCESS—CRYSTALLIZATION

(Ounces of Silver per Ton)

In the molten lead before crystallization	In the crystals	In the liquid lead
205.33	113.74—135.91	298.95
213.49	92.75—109.8	313.83
281.34	119.58—198.33	422.91
288.16	113.74—181.99	446.24
420.57	198.91—	560.57
609.57	586.53—	659.15
615.15	503.99—646.31	655.65

Results from experiment—not particularly concordant.  
 "Berg- und Hutten-männische Zeitung," 1862, p. 251.

Zinc Table for a 30-ton Kettle<sup>1</sup>

## FIRST ADDITION OF ZINC (TO REMOVE GOLD)

Up to 0.10 oz. gold per ton, 250 lb. zinc.  
 From 0.10 to 0.30 oz. per ton, 300 lb. zinc.  
 From 0.30 to 0.50 oz. per ton, 350 lb. zinc.  
 From 0.50 to 0.70 oz. Au, 400 lb. zinc.  
 From 0.70 to 0.90 Au, 450 lb. zinc, etc., etc.

<sup>1</sup> By EURICH, taken from HOFMAN'S "Metallurgy of Lead."

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Second addition to bring silver contents to 40 oz.		Third addition to bring silver contents to 1 oz.		Fourth addition to bring silver contents to 0.1 oz.	
Oz. Ag per ton	Lb. zinc	Oz. Ag per ton	Lb. zinc	Oz. Ag per ton	Lb. zinc
40	15	5	225	0.2	60
50	50	7	265	0.3	75
60	100	10	320	0.4	90
70	160	15	400	0.5	105
80	200	20	450	0.6	120
90	245	22	470	0.7	135
100	285	24	485	0.8	150
110	315	26	500	0.9	165
120	345	28	512	1.0	180
130	365	30	530	1.5	225
140	390	32	540	2.0	330
150	415	34	555	2.5	390
160	440	36	570	3.0	450
170	460	38	585	3.5	510
180	475	40	600	4.0	562
190	495	42	615	Before desilverizing lead must be softened, for copper must be removed completely, arsenic to a trace, antimony to not over 0.75 per cent. Copper and tellurium combine with zinc even more readily than does silver.	
200	515	46	630		
.....	.....	48	640		
.....	.....	50	655		
.....	.....	52	670		
.....	.....	54	680		
.....	.....	56	695		
.....	.....	58	710		
.....	.....	60	734		
.....	.....	62	747		

NEWTON's experiments at Maurer (*Bull. A.I.M.E.*, 1915, p. 474), conclusively showed that 535°C. is the best temperature at which to remove the zinc crusts. CARPENTER and WHITLEY have shown that there is but one chemical compound formed between zinc and silver; this is  $Zn_3Ag_2$ , freezing at 665°C. It is soluble in lead at high temperatures.

### Effect of Impurities on Refined Lead<sup>1</sup>

**Antimony and Arsenic**—render lead hard and less malleable. Said to render lead more easily attacked by hot sulphuric acid when antimony is over 0.2 per cent. This seems unreasonable. For corroding, lead may not have over 0.005 per cent. Sb. Tin, arsenic and antimony are oxidized in that order, and the products from softening lead may be separately worked up for these elements.

**Bismuth**—0.118 to 0.352 makes lead hard, somewhat crystalline and more fusible. Over 0.02 unfits lead for corroding.

**Cadmium**—tends to protect lead against sulphuric acid.

<sup>1</sup> HOFMAN, "Metallurgy of Lead"

**Iron.**—Lead containing 0.07 per cent. Fe does not seem to lose in either softness or malleability. Corroding lead ought not to carry over 0.003 per cent. Fe.

**Nickel and Cobalt.**—These can readily be eliminated by slow fusion.

**Tin**—makes lead light gray, hard and increases fusibility. Is readily removed by heating in air.

**Zinc.**—Corroding lead ought not to carry over 0.003 per cent. Zn.

## TYPICAL LEAD SMELTING FURNACES

	Dimen- sions at tuyères, inches	Blast pres- sure, oz	Smelt- ing col- umn, feet	Capac- ity per 24 hr., tons ore	Remarks
U. S. Smelting Co., Midvale <sup>1</sup>	45 × 160		16-18	200	Mech. feed
Tintic Sm. Co., Tintic, Utah <sup>1</sup>	48 × 160	32-34			Coke, 12 %
A. S. & R. Co., Pueblo, Colo <sup>1</sup>	48 × 148	31		150	Mech. feed
A. S. & R. Co., Denver, Colo <sup>1</sup>	42 × 144	32	18	120-150	
A. S. & R. Co., Murray, Utah <sup>1</sup>	48 × 164	34	20	166	Coke, 12 %
Port Pirie, Australia <sup>1,3</sup>	62 × 212	30	21	150	
A. S. & R. Co., Perth Amboy, N. J. <sup>1</sup>	44 × 128	35	16	140	Coke, 12 %
Laurium, Greece <sup>1</sup>	48 × 160	35-40	20	250-275	Coke, 14 %
Herculaneum, Mo. <sup>2</sup>	42 × 192				
Peñoles, Mapimi, Mex <sup>2</sup>	46 × 162	42	22	150	Coke, 13.1 %
A. S. & R. Co., Perth Amboy, N. J. <sup>2</sup>	42 × 220				
International Smelting, Tooele, Utah	53 × 180			275	Coke, 12 %
A. S. & R. Co., Chihuahua, Mex <sup>2</sup>	46 × 202				

<sup>1</sup> From GOWLAND'S "Metallurgy of the Non-ferrous Metals," p. 155.

<sup>2</sup> Private notes

<sup>3</sup> It would appear that the Port Pirie furnace is the largest operating

**Lead-furnace Top Gases.**—Contrary to the usual opinion, the top gases from lead furnaces do not differ markedly from those from iron furnaces, if care be taken to exclude dilution with extraneous air. Bureau of Mines measurements show from 21.7 to 28 per cent. CO; 11.8 to 15.9 per cent. CO<sub>2</sub>; 0 to 0.9 per cent. H<sub>2</sub>; 0 to 1.7 per cent. O<sub>2</sub>; 57.8 to 62.6 per cent. N<sub>2</sub>. This means that these gases would have considerable calorific power, if undiluted. (*Bur. Mines Serial Paper 2957*, August, 1929.)

**Precipitation of Lead with Sponge Iron.**—Lead chloride solutions even when vigorously stirred must be heated to 60°C. in order to precipitate the lead in less than an hour. As the volume of the lead precipitated is greater than the volume of the iron precipitating it, it is difficult to get all the lead out of the solutions except the precipitate remain high in iron. Some sort of mechanical rabbling arranged together with a counter-current travel of the precipitant is a necessity for commercially

successful precipitation. In the experiments of the Bureau of Mines (*Bull.* 281) a machine of the type of a MacDougall roaster was successful, the sponge iron being rabbled down from one "hearth" to another, while the solution traveled upward.

**Betterton Chlorine Process.**—The best way to remove the saturation zinc from desilverized lead is to pass chlorine through the molten lead. Molten zinc chloride forms on top of the charge, which is finally run off into drums and allowed to solidify. The zinc can also be eliminated in a reverberatory furnace by heating the lead to 1200°F. and blowing air into the bath.

## ZINC SMELTING<sup>1</sup>

**Effect of Impurities in Smelting:**

**Alumina**—may be objectionable, as zinc spinel may be formed.

**Arsenic and Antimony.**—These are partly reduced and volatilized, and appear in traces in the spelter.

**Cadmium.**—Cadmium is more easily reducible and more volatile than zinc, and collects in the first dust and metal, which can then be used as a source of this metal.

**Calcium.**—Lime alone is beneficial, as it tends to decompose zinc sulphide. See **Silica**, below.

**Fluorspar.**—This is an undesirable constituent because it forms fusible slags which attack the retorts.

**Gold and Silver.**—These remain chiefly with the retort residues and can be recovered from them by resmelting.

**Iron and manganese**—should not be present as sulphide, as it corrodes the retort. Also forms fusible slags with silica, which corrode the retort. Ten per cent. Mn + Fe represents about the upper limit of safety.

**Lead.**—The chief objection to lead is that its compounds are reduced and some lead distills over with the zinc.

**Magnesia**—acts much like lime, but magnesian slags are less fusible than calcareous.

**Silica**—is inert alone, of no particular consequence when lime is present, but is harmful if both lime and iron are constituents of the charge since ferrous-lime silicates are extremely fusible.

**Sulphur**—decreases the yield of zinc, since the sulphide is not decomposed by carbon. Ferrous sulphide corrodes the retort.

In general, either highly acid or highly basic charges must be used, there must be a little space above the charge, and the charge should not be too finely pulverized.

The formation of zinc spinel occurs to a larger extent in hand-made than in machine-made retorts; it is diminished greatly by addition of coke to the mass used for making the retorts. During smelting the slag takes up considerable quantities of silica and alumina from the retorts, and a viscous layer, intermediate in composition between the slag and the retort, is formed, which tends to prevent rapid destruction of the latter.

<sup>1</sup> W. R. INGALLS, "Metallurgy of Zinc and Cadmium."

It is only at the higher temperatures prevailing toward the end of the distillation that there is any pronounced destructive action of the slag on the retorts. The absorption of zinc oxide by the clay used for making the retorts, and its fixation as aluminate, increases with the pressure, temperature, and time.<sup>1</sup>

**Miscellaneous Data for Zinc Smelting**  
**BLUE POWDER PRODUCTION (ZINC SMELTING)**

Blue powder	I	II	III	IV	V	VI
Zn. ....	(a)90.11	(b)94.04	(a) 91.50	(c)95.50	(d) 88.80	(e)91.29
Pb. ....	0.82	2 50	0.50	1.50	1.90	1.98
Fe. ....	0.10	0 30	0.18	.....	1.32	0.79
Cd. ....	0.005	1.30	0.50	.....	1.80	0.52
As, Sb. ....	Nil	.....	0.10	.....	Tr.	Tr.
C. ....	3.33	?	?	2.50	4.10	3.11
Insol. ....	.....	0.50	.....	.....	Tr.	Tr.
Zinc ore:						
Zn. ....	47.00	46.60	43.00	50 00	48.50	44.50
Pb. ....	3.80	6.60	1.80	5 50	6.50	9.30
Fe. ....	10.34	5.50	8.40	8 50	8.30	12.50
Cd. ....	0.005	0.06	0.10	?	0.18	0.25
S. ....	1.08	1.80	1.50	?	2.50	3.40
As. ....	Tr.	Tr.	0.05	?	0.02	0.02
Sb. ....	Tr.	Nil	0.03	?	0.04	0.03
CaO. ....	4.00	2.80	3.50	4.00	6.00	4.50
MgO. ....	0.60	0.80	1.20	.....	.....	.....
SiO <sub>2</sub> . ....	10.00	13.80	22 00	6.00	13.80	13.90
	A	B	C	H	I	I

(a) A small portion in the form of ZnO. (b) Metallic zinc, 88.74 per cent.; ZnO, 6.60 per cent. (c) Metallic zinc, 85.34 per cent.; ZnO, 12.66 per cent. (d) Metallic zinc, 79 16 per cent.; ZnO, 11.26 per cent. (e) Metallic zinc, 85.24 per cent.; ZnO, 7.54 per cent.

W. R. INGALLS, "Metallurgy of Zinc and Cadmium."

Residues produced	I	II	III	IV	V	VI
Zn. ....	4.00	2 50	3-7	4.00	3.40	4.20
Pb. ....	5.00	8 50	1 26	10.00	8.10	9.50
Fe. ....	10.55	14.50	?	?	?	?
Ag. ....	0.016	?	?	0.01	0.05	0.085
Cu. ....	0.05	?	?	.....	?	?
Cd. ....	Nil	?	?	.....	?	?
As. ....	Nil	?	?	.....	?	?
Sb. ....	Nil	?	?	.....	?	?
S. ....	?	4.00	?	?	2.10	3.50
CaO. ....	2.50	2.60	?	8 00	?	?
MgO. ....	0.45	1.50	?	?	?	?
SiO <sub>2</sub> . ....	.....	.....	?	17.50	?	?
C. ....	50.00	60.00	?	?	?	?
Al <sub>2</sub> O <sub>3</sub> . ....	.....	.....	.....	?	?	?

On attempting a jiggling of the above, these products were obtained:

<sup>1</sup> *Metall. und Erz.*, 1914, pp 333, 337, 412, 553.

Zn .....	3.87	5.00	6-7	3-15	8.0-12.0	2.50-7.0
Pb .....	24.25	13.16	40-50	4-30	30.0-35.0	10.0-48.0
Ag .....	0.032	0.016	.....	.....	0.04-0.05	0.049-0.16
Fe .....	42.75	20.68	15-20	.....	.....	11 77-24.0
SiO <sub>2</sub> .....	18.66	44.67	15-20	.....	.....	12 75-00

## ROASTING LOSSES

Tests on the roasting losses on zinc ores are given by INGALLS<sup>1</sup> as follows:

	Sample				
	I	II	III	IV	
	per cent.	per cent.	per cent.	per cent.	per cent.
Zinc.....	31.00	41.80	43.93	47.50	42.60
Sulphur...	22.26	27.40	24.95	33.26	29.07
Lead.....	7.50	4.00	7.35	2.15	8.75
Iron.....	4.25	3.00	5.20	13.60	7.50
Lime .....	1.60	1.40	0.10		0.12
Magnesia.	0.65	0.80	0.15	1.20	1.10
Baryta....	24.20	10.55			
Quartz....	2.75	10.20	15.46	1.14	10.00
Total.	94.21	99.15	97.14	98.81	99.14
Loss per cent. Zn.	10.50	10.05	11.25	12.70	12.00
per cent. Ag...	11.77	10.68	12.15	11.22	12.00

For complete desulphurization a temperature of 900°C. (orange color) should be obtained.

<sup>1</sup> INGALLS, "Metallurgy of Zinc."

GASES FROM ZINC RETORTS (LETMATHE)<sup>1</sup>

	Before distilling begins	During distillation				
		1	2	3	4	5
CO <sub>2</sub> .....	15.58	0.48	1.06	0.11	1.10	0.82
CO.....	38.52	not det.	92.16	97.12	not det.	98.04
CH <sub>4</sub> .....	4.17	not det.	.....	.....	.....	.....
H.....	41.70	5.32	1.83	not	det.	0.72
N.....	tr	not det.	1.01	0.41	not det.	tr.

<sup>1</sup> SCHNÄBEL, "Handbook of Metallurgy," Vol. II, p. 108. The Macmillan Co.



COMPOSITION OF ZINC FUME<sup>1</sup>

Zn.....	.....	97.80	29.89
ZnO.....	88.20	.....	57.74
CdO.....	1.46	.....	.....
Pb.....	4.00	0.23	.....
SO <sub>2</sub> .....	4.12	.....	.....
Mn <sub>2</sub> O <sub>4</sub> .....	0.05	.....	.....
Fe <sub>2</sub> O <sub>3</sub> .....	1.50	.....	2.91
Insol.....	.....	.....	9.60
	99.33	98.03	100.14

<sup>1</sup> *Ibid.*, p. 176. As can be seen, this is a most variable product.

## Zinc Distillation Temperatures

According to INGALLS

In the retort: beginning, 781; end, 1188.

In the furnace: 1067; end, 1309.

Interior of furnace near middle wall where the gas is introduced, about 1315°C.

CAPACITY AND WEIGHT OF CYLINDRICAL RETORTS<sup>1</sup>

Length outside, in.	7 in. diam. inside			8 in. diam. inside		
	Outside vol., cu. in.	Inside vol., cu. in.	Wt. lb. (a)	Outside vol., cu. in.	Inside vol., cu. in.	Wt. lb. (a)
46	2926	1693	86.3	3613	2212	98.1
47	2990	1732	88.0	3691	2262	100.0
48	3054	1770	89.9	3770	2312	102.1
49	3117	1809	91.6	3848	2362	104.0
50	3181	1847	93.4	3927	2413	106.0
51	3244	1886	95.1	4006	2463	108.0
52	3308	1924	96.9	4084	2513	110.0
53	3372	1963	98.6	4163	2564	112.0
54	3435	2001	100.4	4241	2614	113.9
55	3499	2040	102.1	4320	2664	115.9
56	3563	2078	104.0	4398	2714	117.9
57	3626	2117	105.6	4477	2764	119.9
58	3690	2155	107.5	4555	2813	121.9

<sup>1</sup> W. R. INGALLS, "Metallurgy of Zinc and Cadmium."

(a) After burning. An old retort will carry 12-18 per cent. of its weight in zinc.

DIMENSIONS OF ZINC RETORTS USED IN THE UNITED STATES<sup>1</sup>

Place	Cross section	Length, in.	Diameter, in.
Carondolet.....	Circular	.....	8
Collinsville.....	Circular	48	8
Friedensville.....	Circular	46	8
Lasalle.....	Circular	54	8½
Jersey City.....	Circular	54	7
Jersey City.....	Elliptical	54	7×9
Peru.....	Elliptical	.....	7½×11
Pulaski.....	Elliptical	.....	8×10
Pittsburgh.....	Circular	46-50	8
So. Bethlehem. . .	Elliptical	51	6¾×12½

<sup>1</sup> W. R. INGALLS, "Metallurgy of Zinc and Cadmium."

**Retort Duty.**—According to INGALLS, a production of about 4½ tons of spelter per retort per year is a safe estimate.

**Glazing.**—Sometimes the retorts are glazed when dry in order to make them impervious to the passage of gas. Lead glazes may not be used; more often porcelain and salt glazes are used. The porcelain glaze consists of 84 parts ground feldspar, 35 parts calcium carbonate, 26 to 91 parts china clay and 54 to 204 parts quartz sand. It is not necessary that the glaze be quite white. The glaze is made into a mixture with gum arabic, dextrine or some other paste and painted on the inside of the retort to a thickness of about ¼ in.

CADMIUM-BEARING FLUE DUSTS<sup>1</sup>

Silesia works				Godulla works			
		Total				Total	
	Solu- ble	Insoluble			Solu- ble	Insoluble	
ZnO. ....	17.144	7.192	24.336	10.991	9.532	20.523	
PbO. ....		6.285	6.285		8.980	8.980	
CdO. ....	0.874	1.147	2.021	120	1.518	2.638	
TlO. ....	0.006		0.006	006		0.006	
FeO. ....	1.898		1.896	676		1.678	
MnO. ....	1.332	0.042 (Mn <sub>2</sub> O <sub>3</sub> )	1.376	481	.591 (Mn <sub>2</sub> O <sub>3</sub> )	2.072	
Fe <sub>2</sub> O <sub>3</sub> . ....	2.900	9.043	15.058	940	15.928	18.868	
Al <sub>2</sub> O <sub>3</sub> . ....		3.115		191	4.601	5.792	
CaO. ....	0.714	0.478	1.192	464	1.071	1.535	
MgO. ....	0.168	0.440	0.608	337	0.858	2.195	
As <sub>2</sub> O <sub>3</sub> . ....		0.401	0.401		1.280	1.280	
P <sub>2</sub> O <sub>5</sub> . ....		0.263	0.263		0.394	0.394	
SO <sub>2</sub> . ....	20.430	6.612	27.042	13.320	9.061	22.381	
H <sub>2</sub> O. ....	11.400	.....	11.400	850	.....	4.850	
Residue. . .		7.765	7.765		6.804	6.804	

<sup>1</sup> SCHNABEL'S "Handbook of Metallurgy." The Macmillan Co.

**Spiegel Smelting.**—G. C. STONE says that the manganese in the slags from spiegel smelting is at a minimum when the O

of the  $\text{SiO}_2 + \frac{1}{2}\text{O}$  of the  $\text{Al}_2\text{O}_3$  is equal to the O of the  $\text{CaO} + \text{MgO}$ . (Discussion of paper by PHILIP S. MORSE, February meeting, A.I.M.E., 1929.)

**Zinc-oxide Making.**—G. C. STONE says that in burning ores for the production of zinc oxides, a minimum of zinc will be left in the ore if O of the  $\text{SiO}_2 + \frac{1}{2}\text{O}$  of the  $\text{Al}_2\text{O}_3$  is equal to O of  $\text{CaO}$ ,  $\text{MgO}$  and  $\text{MnO}$ . (Discussion of paper of P. S. MORSE, February meeting, A.I.M.E., 1929.)

**Fuming Off Zinc from Lead Slags.**—At East Helena, Mont., lead-furnace slags, containing 12–15 per cent. zinc, are treated for its recovery. The furnace is water jacketed,  $8 \times 12$  in. area, with a charge hole in one end into which is poured liquid slag from the lead furnaces. At the other end is the tap hole. The bottom of the furnace is made of water-cooled cast-iron plates and about 4 in. above these plates are the tuyères, 11 on a side, 4 in. in diameter. Each tuyère contains a  $\frac{1}{4}$  in. coal pipe, for feeding coal into the blast air. The charge hole is 15 ft. above the furnace bottom. Above the charge hole is a rectangular canopy of water jackets which confine the gases so that they may be conducted into a dust-collecting system. Then comes a horizontal flue of water jackets,  $8 \times 8 \times 34$  ft. This flue is provided with adjustable openings through which air is admitted to burn the zinc vapor to zinc oxide. The powdered coal is delivered by screw to an injector where it is picked up by air at 90 lb. pressure. The time of blowing a charge is from 100 to 160 min., and the depth of liquid bath in the furnace is about 3 ft. From 20 to 35 per cent. of coal is used. It is not economical to try to extract over 85 to 90 per cent. of the zinc (*A. LAIST, Eng. and Min. Jour.*, Aug. 24, 1929).

**Electrolytic Lead Refining.**—In a refinery operating under commercial conditions the ampere efficiency in lead deposition was 88.5 per cent. with a deposit of 20 lb. per kilowatt-hour. The current density used was 16.7 amp. per square foot. Anodes were spaced  $4\frac{1}{2}$  in. from center to center. Starting sheets were cast by allowing molten lead to flow down an inclined cast-iron plate. Electrolytic lead refining must be made to pay through its byproducts, particularly bismuth, and it seems questionable whether it can be adapted to a low-bismuth bullion.

TYPICAL ELECTROLYTIC LEAD REFINERY MATERIALS

	Pb, per cent.	Ag, oz. per ton	Au, oz. per ton	Bi, per cent.	Cu, per cent.	As, per cent.	Sb, per cent.	Te, per cent.
Anodes.....	97.79	139.9	1.52	0.21	0.065	0.85	0.52	0.011
Slimes.....	13.52	4949.2	40.69	4.81	1.45	17.36	22.75	0.45 <sup>1</sup>
Electrolyte.....	8.32	.....	.....	0.00058	0.00049	0.0008	0.012	..... <sup>2</sup>
Refined lead.....	.....	0.29	Tr.	0.0024	0.001	Tr.	0.0066	.....
Slag, slimes smelting....	37.50	313.0	0.72	1.68	2.65	6.75	22.92	.....

<sup>1</sup> These slimes were largely produced from the anodes just above. •

<sup>2</sup> Carries also 11.78 per cent.  $\text{H}_2\text{SiF}_6$ ; 0.36 per cent. HF; 0.28 per cent. Zn; 0.44 per cent. Sn.

## Electrolytic White Lead

The Sperry electrolytic white lead process is operated by the Anaconda Copper Mining Co. The anode is lead, the cathode is iron, the cell is a diaphragm cell, the anolyte containing sodium acetate and a small amount of sodium carbonate; the catholyte containing sodium acetate and a relatively large amount of sodium carbonate.

The action occurring when the current is applied may be described, simply, as follows: The lead is dissolved from the surface of the anode, electrolytically, as lead acetate and is immediately reprecipitated as insoluble basic carbonate,  $2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$ , by the sodium carbonate in the anolyte, thus restoring the sodium acetate but depleting the anolyte in  $\text{CO}_3$  ion. The proper concentration of  $\text{CO}_3$  is restored and maintained constant by passage of this ion through the diaphragm from the catholyte, which in turn becomes impoverished in  $\text{CO}_3$ . The anolyte enters the cell clear and leaves carrying the white lead in suspension, but with no change in composition. The catholyte enters the cell high in  $\text{Na}_2\text{CO}_3$  and low in  $\text{NaOH}$ , and leaves low in  $\text{Na}_2\text{CO}_3$  and high in  $\text{NaOH}$ . The  $\text{CO}_3$  is restored by carbonating the catholyte at one point in its circulation outside the cell.

The white lead produced in suspension in the anolyte is removed from the cell continuously by the circulation of the anolyte. It is separated from the solution by settling and filtration and the clear anolyte is returned to the cell. The white lead thus removed is washed, dried, pulverized, and barrelled for market.

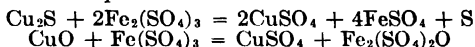
	Anodes	Anode Slime
Ag, oz. per ton	0.29	33.3
Pb, per cent.	99.87	66.17
Sb, per cent.	0.012	1.86
As, per cent.	0.0065	0.08
Cu, per cent.	0.0004	0.06
Zn, per cent.	0.0029	0.40
Bi, per cent.	0.111	10.35
New anode weight		250.0 lb.
Scrap anode weight		75.0 lb.
Time of corrosion		85 hr.
Cell voltage		3.5
Current density, amp. per sq. ft.		29.6
Current efficiency		97.0
Anolyte temperature, deg. C.		40.0
Thickener feed, per cent. solids		0.50
Thickened pulp, per cent. solids		30.00
Washed filter cake, per cent. solids		55.00
Dried product, per cent. $\text{H}_2\text{O}$		0.20
Drier temp., max., deg. C.		120.0

The tanks are reinforced concrete covered with asphalt. The fittings are hard rubber, including the diaphragm supporting frame. Launderers are wood with soft sheet-rubber linings.

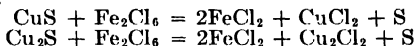
The cells are  $24\frac{1}{4} \times 54 \times 33\frac{5}{8}$  in. with a shallow hopper bottom. There are 18 anodes, spaced on 3 in. centers, with 17 cathodes. The diaphragms are of tightly woven linen duck.

### Copper Leaching

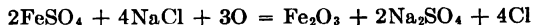
In general, leaching processes fall into 12 distinct groups: (1) Oxidation of sulphides in the ore with formation of water-soluble sulphates. This may be slow, going on at ordinary temperatures; or a quick sulphatizing roast. This latter, in turn, may be either an oxidation of sulphides already present in the ore, or with addition of pyrite material, such as was tried in the Shannon Copper Co.'s experiments. However, owing to the formation of basic compounds, the products of the sulphatizing roast must ordinarily be treated with dilute sulphuric-acid solution, so that this process grades into: (2) Leaching of oxidized ores or calcined sulphides with sulphuric acid, in which category come the successful operations of the Anaconda Copper Mining Co., the Chile Exploration Co.'s plant at Chuquicamata, the New Cornelia Copper Co. at Ajo, Ariz., the Arizona Copper Co.'s leaching plant at Clifton, and the Butte-Duluth and Steptoe plants. Somewhat akin to these is: (3) The use of soluble persulphates, of which iron is the only practical example, as a solvent. The Siemens & Halske process is the classic example of this:



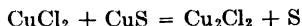
(4) Closely allied to (2) is the process used at Stadtberge and Linz, Germany, in which oxidized ores were treated with sulphur dioxide and nitrous bases. Intermediate between two main groups of sulphate and chloride leaching stands: (5) the Dötsch process, used at Río Tinto, Spain. In this process, ferric sulphate and salt are the reagents, the equations being essentially:



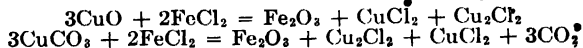
The liquor is regenerated, after precipitation of the copper, by running it down through chlorine towers, the gas being produced by heating salt and ferrous sulphate in an oxidizing atmosphere in reverberatories:



The Hunt-Douglas process also falls into the same class. Among the chloride-leaching processes the use of (6) hydrochloric acid has been proposed but does not seem to be in commercial use anywhere at present. (7) Höpfner uses cupric chloride:



while the use of ferrous chloride is theoretically attractive:



Practically, however, the reactions are slow, precipitation of the copper expensive, and regeneration of the "le" salts incomplete. (8) The Longmaid-Henderson process first calcined the ores, then roasted with *abraumsalz*, a mixture of sodium, potassium, magnesium and calcium chlorides. In an absolutely different class of reagents come: (9) Ammonium carbonate or (10) ammonia. The great difficulty with these processes has been the loss of the reagents by volatilization, but the ammonia-leaching process is very successfully used both by Calumet & Hecla, and Kennecott, the first on tailings containing native copper, the other on ore. (11) Last is the theoretically beautiful leaching with sodium thiosulphate, which appears to be a practical failure through the ready decomposition of the reagent and the inhibitory effects of calcium compounds. (12) Leaching with nitric acid was tried by the Nevada-Douglas Copper Co. at Ludwig, Nev.

Any review of leaching would be incomplete without some reference to the ingeniously worked out Bradley process.<sup>1</sup> The ore was carefully roasted to a sulphate and most of the iron was converted into insoluble ferric oxide. This must be done at temperatures between 450°C. and 550°C. The roasted ore was then brought into association with an excess of calcium-chloride solution in a reaction drum at about a temperature of 100°C. Cupric chloride was produced by the reaction between the copper sulphate and the calcium chloride, while any ferric sulphate in the roasted product reacts with the calcium chloride to produce ferric chloride. The calcium sulphate from both these reactions is of course insoluble and is separated by filtration in the succeeding step.

From this solution the iron and alumina was precipitated by cupric oxide, hydrate, or calcium carbonate, which carries down some copper. This precipitate was therefore returned. to the sulphatizing-roasting process, in which the bulk of the iron and alumina were rendered insoluble, while the copper was converted into soluble copper sulphate.

The solution from which the iron and alumina had been removed and which contained the bulk of the copper was run into a second tank in which copper was precipitated by calcium carbonate as oxide of copper. The precipitate was filtered off and the copper recovered, while the calcium chloride was regenerated for use on further quantities of ore. There were also modifications for recovery of the silver, gold and zinc in the ore. Apparently its own chemical complications caused its failure.

In the consideration of any leaching process the first factor is the character of the ore. Thus, an ore containing large amounts of calcium carbonate obviously cannot be successfully leached with any free-acid reagents. The same would equally apply to ores containing large amounts of soluble alkalies, magnesia, alumina, etc. The leaching agent will be determined partly by the character of the ore and partly by its own cost. The reagent most generally available and cheapest is sulphuric

<sup>1</sup> U. S. Pat. No. 1,011,502.

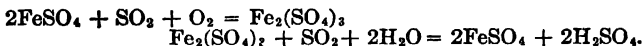
acid. Ample wash water is a *sine qua non*, while the last great question is that of a precipitating agent. On this we are at once reduced to iron, sulphur dioxide under pressure, electrolysis and calcium carbonate or hydrate.

Scrap iron, after the floating supply of tin cans has been utilized is likely to be an expensive commodity. Using a fairly pure copper sulphate solution, the consumption of iron is likely to run from  $1\frac{1}{4}$  to  $1\frac{1}{2}$  lb. of iron per pound of copper produced. Where the solutions are high in chlorides, as in the Dötsch process at Rio Tinto, the consumption of iron is said to run as high as  $2\frac{1}{2}$  lb. of iron per pound of copper produced. However, the possibilities of sponge iron, *i.e.*, iron produced by the reduction without fusion of ferric oxide, have by no means been exhausted.

Electrolysis has been very successful in the immense installations of the New Cornelia and Chile Copper Cos. and seems to be the best bet for precipitation.

**Precipitation of Copper with Sponge Iron.**—An excess of  $7\frac{1}{2}$  per cent. of sponge iron over that required stoichiometrically to precipitate the copper is usually sufficient. Little advantage was gained by adding over 15 per cent. excess. Over 80 per cent. of the copper is usually precipitated in 2 to 4 min. Increase in acidity slows down the rate in rich solutions, but increases it in poor. Precipitation with the air excluded just as far as possible is recommended by the Bureau of Mines (*Bull.* 281) as minimizing resolution of the copper.

**Ferric Sulphate-sulphuric Acid Process of Copper Leaching.**—Fundamentally, the process consists in bubbling gas mixtures obtained from a roaster through a ferrous-sulphate solution such as results when copper is precipitated from a sulphate solution by metallic iron, to obtain a mixture of ferric sulphate and sulphuric acid, which is used as the leaching solution. The equations are:



Eventually the two equations proceed simultaneously. The Bureau of Mines (Serial No. 2839, Nov. 1, 1927) states that at least up to  $80^\circ\text{C}$ ., the higher the temperature, the more rapidly may the iron be oxidized. At  $40^\circ\text{C}$ . there must not be over 10 grams free sulphuric acid per liter in the completely reduced solution to be oxidized, and there should be at least three times as much oxygen as  $\text{SO}_2$  in the gases being led into the solution. The maximum capacity for converting  $\text{SO}_2$  is found when the iron concentration is about 5 grams per liter.

The process of leaching with ferric sulphate has been tried on a large scale by the Inspiration Copper Co. (G. D. VAN ARSDALE, *Trans. A.I.M.E.*, February meeting, 1926). He states that contrary to the textbooks, much more than half the copper of  $\text{Cu}_2\text{S}$  is soluble in ferric sulphate solution and that a reasonable regeneration of ferric sulphate can be conducted in a non-diaphragm cell.

VAN ARSDALE experimented with both graphite and lead anodes. The former gives a low overvoltage and as high efficiency of conversion of ferrous to ferric iron as compared with lead but to get minimum voltages agitation and high temperatures are necessary. About 15 amp. per sq. ft. are necessary to prevent solvent action at the cathode by the regenerated iron. For electrolysis the following limits were found desirable: Cu (as sulphate) 2.5–3.5 per cent.; total Fe, 1.5–2.5 per cent.; ferric Fe up to 1.0 per cent.; free acid 3.5–7.5 per cent. maximum. About 0.5 per cent of the copper can be plated out as reguline copper. Below 0.4 per cent.  $\text{Fe}'''$ , the solvent action of ferric iron is feeble; at over 0.75 per cent  $\text{Fe}'''$  it is active. Therefore, while it is theoretically possible to obtain a complete reduction of ferric iron during leaching, it is very inadvisable to do it.

Leaching was by counter-current contact continued 9 days on three-mesh ore, followed by six washes taking three days. The strongest wash water was added to the copper solution in the tank house. The tailings ran about 0.2 per cent. Cu.

**Ammonia Leaching of Calumet & Hecla Tailings.**—These tailings contain only native copper and no sulphide or oxide minerals, and there is about 2 per cent. of +28 and 15 per cent. of -200-mesh material present. A solution of copper ammonium carbonate is employed as the leaching agent and as much of the copper as possible is in the cupric state when the solution is passed over the ore, since the essential reaction is that between the cupric ammonium carbonate and metallic copper giving cuprous ammonium carbonate, soluble in excess of ammonium carbonate and ammonia.

After solution is over and the rich solution drawn off the exhausted tailings, a portion of the solution is distilled precipitating copper oxide and volatilizing ammonia and carbon-dioxide. The remainder of the solution is reoxidized to the cupric state and the recovered ammonia and carbon dioxide from the distillation added to it.

Leaching is done in steel tanks, 54 ft. in diameter  $\times$  12 ft. high. During leaching the tanks are kept covered by a trussed steel lid, which fits into an annular launder filled with water, thus avoiding ammonia losses. The leaching solution carries 30 grams of copper and 60 grams of ammonia per liter and passes through the tailings by downward percolation. The first effluent is sent to the distilling apparatus as it is stronger in copper and more thoroughly reduced than is the solution coming through later. The later effluent is oxidized by flowing it down through a tower with grids through which passes an upward current of air. The exhaust air passes through and absorption tower to recover any ammonia carried off.

The exhausted tailings are given a wash with a solution high in ammonia and low in copper, then with water, and are then given a steaming to remove adherent ammonia. The tailings are on a filter bottom and air is exhausted from under the bottom, steam being admitted above the sand at atmospheric pressure or a little above.



Distillation takes place in two stages, the first a still in which scrapers remove the precipitated oxide and hydroxide of copper; the second a still to remove the last of the ammonia and carbon dioxide with a comparatively small deposition of copper oxide.

1923 costs	First half	Second half
Tons sand treated. . . . .	741.000	923.130
Lb. Cu produced. . . . .	6,171.000	7,454.000
Cost per ton sand, cents. . . . .	36.73	32.25
Cost per lb. Cu, cents. . . . .	4.41	3.99
Lb. Cu recovered per ton . . . . .	8.33	8.07
Assay of oxide, Cu. . . . .	82.05	82.55
Assay feed. . . . .	0.521	0.507
Assay tailings . . . . .	0.108	0.103

Ammonia losses amount to about 8 cts. per ton of sand, with ammonia at 18.5 cts. per lb.

**Tailing Leaching at Anaconda (1916).**—The tailings are roasted in 20-ft. diameter externally fired six-hearth McDougall furnaces, the roasted tailings going through a cooler and then through a concrete lined cylinder where it is mixed with water so that a moist warm calcine is delivered to the leaching vats. These are redwood tanks 50 ft. in diameter  $\times$  14 ft. deep holding about 1,000 tons of calcine. The tanks are built with a filter bottom, made of  $1\frac{1}{4}$  in. slats on  $2 \times 4$ -in. pieces. Above this are two layers of heavy cocoa matting and on top of the matting is a grating made of  $1\frac{3}{4} \times 3\frac{1}{2}$ -in. boards with 6-in. square spaces. These fill with calcine and prevent the sluicing water from tearing the matting, which is rotted by the solutions used, but is an efficient filtering medium after it is rotted. Lead pipes are used for the leaching solutions, with "acimet" valves. The floors of the leaching and solution buildings are of concrete, painted with an asphalt-tar mix for acid proofing. Precipitation is on scrap iron in concrete launders, 250 ft. long, with a section  $4 \times 8$  ft. There is a heavy grating on which the scrap iron rests, with a 6-in. space underneath it.

The roast is a simple oxidation. The hottest floor in the furnace is about 535°C. This is the third floor (externally fired). Leaching is by downward percolation of solutions at about 50°C.

	Cu, per cent.	H <sub>2</sub> SO <sub>4</sub> , per cent.	NaCl, per cent.
No. 1 Solution . . . . .	0.8	5.0	7.0
No. 2 Solution . . . . .	0.1	0.5	3.5
Copper-solution tank . . . . .	1.9	1.0	7.0
Wash-water tanks . . . . .	0.2	1.0	1.0

coming off the newest charge and going to the reduction towers is known as the "neutral advance."

Upon the entrance of a new charge into the circuit the solution remaining in the oldest tank is drained to the solution storage, where it is standardized with acid and is later used as acid advance. After thorough draining the tank is ready for the wash water.

As the copper entrained in a charge after leaching is about one-third of the total copper dissolved, the question of thorough washing is very important. Four successive wash waters with drainings are used.

The fourth wash of any one charge is used as the third wash of the succeeding charge, the third used as the second and the second as the first. In other words, each wash water is used four times, the copper contents increasing each time, when it is incorporated into the system to make up the continuous losses of solution. These losses are due to evaporation, discard, and solution entrained in tailings.

After a charge has been washed and drained, the tailings are removed from the tank by a Hulett unloader, similar to unloaders used on the Great Lakes for unloading iron ore from boats. A heavy steel bridge on trucks spans the leaching tanks and travels their entire length. On this bridge travels a trolley carrying a walking beam, bucket leg, and bucket of 12-ton capacity. The unloader has a rated capacity of 500 tons per hour and will generally excavate a tank of tailings in 10 to 11 hr.

**Reduction of Iron.**—In the electrodeposition of copper from a sulphuric acid solution, iron, if present, will consume electric energy, by its alternate oxidation and reduction, thereby reducing the quantity of copper deposited per unit of current. During the experimental work the control of the ferric iron proved one of the hardest problems to solve. A patent diaphragm anode was tried and gave good results, but was cumbersome and difficult to keep in order. Later, tests made on a process in which iron and alumina were precipitated as hydrated oxides by the addition of roasted copper ores gave good results. This method was considered too complicated for an ore of this character. The idea was then suggested of using the natural oxides and carbonates in the ore itself as the precipitant of the ferric sulphate; in other words, the precipitation of the principal impurities in the solutions upon the charge itself. Early tests made on a small scale were very promising, but tests carried out later on a larger scale failed to give the desired results. For the first 15 or 20 days, the copper in the newest charge of ore was sufficient to precipitate all the ferric iron that was contained in the solution passing through the ore. However, as the acid concentration on each charge increased, the precipitated ferric iron was redissolved and eventually accumulated to such an extent that the iron in the solution was in excess of the copper available as precipitant.

It was then decided to resort to  $\text{SO}_2$  reduction. The general opinion was that this was both unsatisfactory and difficult.

This proved to be the case in solutions decidedly acid, but where neutral or slightly acid solutions were used, reduction proved quite easy.

The solution (or neutral advance) to be reduced travels countercurrent to the flow of gas, that is, the most reduced solution comes in contact with the strongest gas. The solution coming from the newest tank of ore is pumped to the top of the third pair of towers by a centrifugal pump. The solution distributed by launders and gas seals flows down over the filling, thus coming into intimate contact with the rising gas. At the bottom of each pair of towers there is a concrete lead-lined sump, into which the solution flows and is then pumped through the next pair of towers. From the first pair of towers the solution is pumped to the second pair, then to the third pair, and then to the so-called settling tank, whence it goes to the tank house. The purpose of this settling tank is twofold: one, to settle out the slime; the other, to get the benefit of the additional reduction that was found to take place in a neutral or slightly acid solution on standing.

The electrolytic tanks are housed in a structural-steel building, 166 ft. wide and 280 ft. long, having sides only partly enclosed to give good ventilation. The tanks are all on the same level, none in cascade.

The cellar, which is open on all sides, has an asphalt floor draining to gutters that lead to a sump at each end of the building. There is head room throughout the cellar to permit regular inspection of tanks, piping, and feed wires.

The electrolytic tanks are arranged in banks with aisles between. There are twelve banks of ten tanks each and four banks of eight tanks each, making a total of 152 tanks. Each tank is separated from the adjacent tank by a 3-in. air space. All tanks are made of Oregon pine, lined with 7-lb. chemical lead. The inside dimensions of the tanks are 29 ft. 7 in. long, 4 ft. 9 in. wide, and 4 ft. 3 in. deep. These tanks are supported on concrete columns, and are insulated by tile blocks covered with sheet-lead caps. Each tank is provided with a 4-in. clean-out plug. There are also two perforated lead diaphragms, one at each end of the tanks, to assure a uniform circulation. The inlet to each tank is fitted with a 3½-in. diaphragm valve and a 3½-in. glazed stoneware gooseneck for insulating purposes. At the outlet end there is a lead overflow pan fitted with a 4-in. tile pipe suspended in a 10-in. lead boot connected to the discharge pipe.

Each tank has 84 anodes, making a total of 12,768 in the tank house. The anodes are of lead containing 3.5 per cent. antimony. The average weight of a lead anode is 215 lb. They are 40 by 51 by ¼ in. thick, and are suspended by two ¼-in. copper bars secured to the tops of the anodes. The submerged surface of all anodes is 41 by 41 in. The spacing of anodes is 4½ in. on centers. The distance from the bottom of an anode to the bottom of the tank is 8 in., while that of the cathode is 7 in. Short circuits are prevented to some extent

by providing the anodes with eight chemical glazed-porcelain insulators distributed over the anode faces.

Much doubt was expressed about the life of the lead anode and some very positive statements were made regarding their probable length of life. Continuous service extending for over a year has failed to show appreciable oxidation.

There are 77 cathodes to a tank, or 9,779 cathodes in the tank house, exclusive of starting-sheet blanks. The cathodes, which are 42 in. square, are totally submerged. They are suspended upon copper bars by loops made from starting sheets. The original starting sheets weighed about 15 to 18 lb., while the finished cathodes weigh 130 to 140 lb. At present 127 tanks are used for making cathodes and about 14 to 16 days are required to produce cathodes of the desired weight.

One section of eleven cathodes is removed at a time and carried to the center aisle, where they are washed with hot water to remove the salts and soluble copper. They are then landed on an iron frame to facilitate the hand trucking to the freight cars. Each car is sampled by drilling every twentieth cathode in the center and in diagonally opposite corners. All electrolytic copper, whether cathode or scrap, is shipped to a refinery, where it is melted, brought up to pitch, and cast into commercial shapes.

The cathodes produced have varied from 99.15 to 99.85 per cent. in copper content, the impurities being principally slimes, held by mechanical entanglement. The greater the density of the electrolyte the lower is the copper content in the cathodes, and the greater the insoluble matter, iron, and alumina. The cathodes always contain more or less chlorine, varying from 0.05 to 0.35 per cent. There being no arsenic or antimony in the ore, and very little in the acid, the average arsenic content of the anodes is less than 0.0015 and the antimony less than 0.0005 per cent.

Twenty-five tanks operate on starting sheets, each tank containing seventy-seven starting blanks, or a total of 1,925 blanks. The starting blanks are of rolled 3.5 per cent. antimonial lead, 53 by 43 by  $\frac{1}{4}$  in., and are large enough to allow a small amount of trimming, which is done with a squaring shear. The anodes in these tanks are 3.5 per cent. antimonial lead, and are 41 by 52 by  $\frac{1}{4}$  in. They do not have porcelain insulators, as these tend to spot the starting sheets. The spacing of anodes in these tanks is the same as in the commercial tanks. The tank construction and other details are likewise similar.

Eleven blanks are handled at one time by the crane, and placed on an iron stripping rack provided with a crawl so that the blanks can be carried, one at a time, to the center of the rack, where the starting sheets are removed by two strippers, one stripping from each side. After stripping, the blanks are oiled and placed on the opposite end of the rack to be returned by the crane to the tanks.

The electrodes hang parallel to the flow of solution (or parallel to the length of the tanks) to give a free circulation of the electrolyte.

Alternate busbars extending across the tanks connect the electrodes in parallel and the tanks in series. These busbars, placed across the tank, divide it into seven sections or cells. The intermediate busbars are  $1\frac{1}{2}$  in. wide and 4 in. deep, while the end busbars are 1 in. wide and 4 in. deep. Soldered along the top of each busbar is a triangular piece of copper,  $\frac{1}{2}$  in. high, giving a point contact to the electrode bars. Small maple blocks impregnated with linseed oil insulate cathodes and anodes from opposite busbars. These busbars are supported on insulated iron castings, which, in turn, rest on the tank cleats. The current for the deposition of the copper is supplied to the tank house by two identical 15,000-amp. circuits, each circuit having seventy-six tanks in series. This arrangement gives the maximum current density of 8 amp. per square foot of cathode surface when operating under normal conditions. With an average current efficiency of 80 per cent. this means a daily gain of about 10.25 lb. per cathode, or a total capacity of 120,000 lb. of electrolytic copper per day. The drop of potential between anodes and cathodes has averaged very close to 2.00 volts. There is a tendency for the voltage to drop during the summer due to an increase in the temperature of the electrolyte.

The solution flow in the tank house is part of a closed circuit with the leaching and reduction plant, receiving a continuous flow of solution from them. This flow, coming always off the newest ore, then through the towers and settler, is regulated by means of weirs and has varied from 800 to 1,500 gal. per minute, depending on operating conditions. This volume is divided among the sixteen banks of tanks, those on starting sheets getting generally a little more than those on cathodes. By this arrangement each bank of tanks on cathodes receives between 60 and 70 gal. per minute of reduced solution. Each bank unit consists of either eight or ten tanks, a sump, and a 9-in. vertical-type centrifugal pump having a capacity of 1,600 gal. per minute. Each bank has an individual circulation of 1,600 gal. per minute between it and the sump, while an overflow arrangement provides for the return of such a portion of the electrolyte as is equivalent to reduced solution added.

The current efficiency depends on the quantity of ferric sulphate present, due to the reaction between ferric sulphate and metallic copper. The ferric iron content in the solution is kept as low as possible and the conditions shown are as good as can be expected. No doubt, with a smaller quantity of total iron present in the solution less would be oxidized, and it was recommended that the total iron be kept below 2 per cent. With the total iron not over 2 per cent., the ferric iron in the electrolyte will probably not exceed 0.5 per cent., the current efficiency will be increased, and more acid will be regenerated.

At the beginning of operations in the tank house, a great deal of difficulty was encountered by the dropping of cathodes in the electrolytic tanks, due principally to the corrosive action

of the ferric sulphate on the loops at the solution level, and on that part of the cathode covered by the ends of the loops. Corrosion at the solution line was easily remedied by raising and lowering the solution level in the electrolytic tanks, but the corrosion of the cathode sheet between the loop ends was far more difficult to overcome. Later, this condition became worse with the increase in the ferric iron and higher temperature of the electrolyte. The dropping of cathodes not only caused bad short circuits in the tanks, but also made it necessary, when pulling cathodes for shipment, to pull individual sheets with tongs, which made it almost impossible to handle the daily output of cathodes. Considerable damage was also done to the lead lining of the tanks and the danger from accidents was more than usual. Numerous schemes to overcome this difficulty were suggested and tried, until it was found that, by splitting the ends of the loop and attaching them with a Morrow machine in such a manner that the portion of the starting sheet adjacent to the loop was exposed to the deposition of copper, not only the loop, but also the sheet built up, making a good firm joint. Since the adoption of this method no further trouble has been experienced with dropping sheets. Patents have been applied for and allowed covering this improved loop.

Only about 45 to 50 per cent. of the total acid used in an 8-day leach is utilized in dissolving copper. The remainder is used in dissolving impurities. If copper only is removed from the solution, the other substances will gradually accumulate and the solution will reach a condition where it will become sluggish in dissolving the copper from the ore. To keep the solution active, it is evident that a portion must be discarded and replaced with fresh water. The quantity of solution discarded per day must contain impurities equivalent to the amount dissolved per day, if the accumulation is to be avoided. In the experimental work it was found that, under similar conditions, nearly all the substances that went into the solution were present in a fairly constant ratio to one another. Of the various impurities dissolved, iron is the most easily and quickly determined and was used as the indication of the quantity of solution necessary to be discarded. The experimental work clearly demonstrated that the best results are obtained when the total iron in the solution does not exceed 2 per cent.

The original cementing equipment consisted of six sections of reinforced-concrete launders. These are arranged in two parallel rows of three sections each. The bottom of each launder slopes toward three side clean-out gates. The scrap iron rests upon a grated wood floor. The solution flows through each one successively, but may be by-passed to allow the cleansing and refilling of any of the sections. From these launders the waste solution was to go to the desert.

Under good operating conditions practically all the copper is precipitated. When a launder is no longer efficient, the solution to that launder is by-passed and the solution remaining in it is drained. The cement copper is shoveled out onto wooden

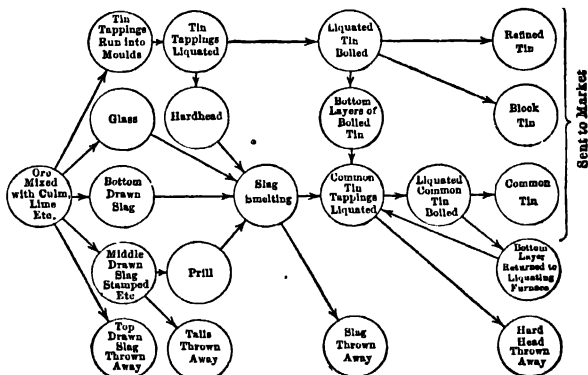
grates, where the iron is washed off with a hose, and the unconsumed iron is returned to the launders.

Cement copper when clean and finely divided dissolves readily in ferric sulphate, with the formation of copper and ferrous sulphates. By so doing not only is the cement copper dissolved, but the ferric iron is reduced also. The plan was to hose off the loosely adherent copper from the scrap iron to the bottom of the tank and then flush it into one or more circular lead-lined tanks, called agitators. These tanks are 20 ft. in diameter and 6 ft. deep, provided with a stirring device, driven by a small motor; 125 gal. per minute of tank-house return solution can be circulated through each tank.

This plan of redissolving the cement copper is carried out when the operating conditions of the plant require it. The principal objections to the continuous use of such a plant are that, by redissolving the cement copper in tank-house solution the total copper output of the plant is reduced, which at times does not give the greatest profit possible.

### TIN SMELTING

In British practice with ore assaying 65\* to 71 per cent., the charges are: Ore, 80 cwt.; culm, 10.4 cwt.; refinery dross, 2.4 cwt. For ore above 71 per cent. increase the culm. This



Flow sheet, tin smelting.<sup>1</sup>

will give from 4500 to 4800 of tin assaying about 99.5 per cent. of tin, and 2200 lb. of rich slag, carrying 35 per cent. of tin. This slag is then smelted as follows: Rich slag, 30 cwt.; rough-metal dross, 12 cwt.; scrap iron, 2.75 cwt.; anthracite, 6 cwt.; coal, 2.4 cwt. It may be noted in operations where tin

<sup>1</sup> From Louis, "Metallurgy of Tin," p. 96.

is on the furnace charge, that it will be carried into either too silicious or too basic a slag, as it forms silicates and stannates and stannites.

**Slag for Tin Smelting.**—In order to produce a slag low in tin, H. H. ALEXANDER recommends the following blast-furnace slag composition:  $\text{SiO}_2$ , 37.0 per cent.;  $\text{FeO}$ , 23.4;  $\text{CaO}$ , 23.0;  $\text{Al}_2\text{O}_3$ , 12.0;  $\text{MgO}$ , 3.0 per cent. Considering  $\text{Al}_2\text{O}_3$  as an acid, this is practically a bisilicate.

### Tin Smelting by Electricity

The electric furnace should be appropriate for the smelting of tin ores, since the reduction of tin oxide by carbon requires a very high temperature especially if impurities are to be eliminated. The reduction by carbon produces partly carbon dioxide and partly carbon monoxide, and theoretically would require 665 kw.-hr. per ton of ore. The theoretical amount of energy per ton of ore smelted may be estimated as follows:

Reduction.....	665 kw.-hr.
Slag.....	130
Heating tin.....	65
Radiation.....	130
Gases.....	150
Total.....	1140 kw.-hr.

Experiments on tin smelting, conducted by H. HARDEN in Cornwall, were described in the *Mining Journal* of London, in 1914. The current was a three-phase, alternating, of 50 cycles, 650 to 675 volts. A shaft furnace was used containing 3 electrodes and the formation of a direct arc was avoided. The charge formed a cone around the reaction zone, in which the electrodes burned freely, surrounded by incandescent gases which served as resistance. The three factors, yield of tin, consumption of energy, and losses in slag, are closely interrelated. It is easy to obtain a slag containing only 0.25 per cent. of tin, but the process is not economical, as the consumption is 3000 kw.-hr. per ton of metal. When the slag contains 17 to 19 per cent. of tin the consumption of energy is reduced to 1300 kw.-hr. per ton of metal, but this is not economical. On a recovery of about 96.75 per cent. of the tin in the ores, the consumption was 2200 kw.-hr. per ton of metal. The consumption of electrodes was 12.7 kw. per ton of metal. Arsenides and sulphides of iron were introduced at regular intervals to avoid the formation of hard slag, obtaining a metal containing 98 per cent. of tin from very impure ores. This metal was afterward refined in shaft furnaces containing iron tubes for the injection of air. HARDEN's conclusions are that the electric process can be advantageously employed in places where the ores are good but not very rich, and where waterfalls can be utilized for supplying the power needed.



## NICKEL-COBALT-COPPER SMELTING

In smelting nickel, copper and cobalt together under such conditions as to form a matte and a speiss, it is the general tendency of the copper to enter the matte in preference to the nickel, and for the nickel to enter it in preference to the cobalt. Some subjoined analyses from SCHNABEL illustrate this very well. The furnace charge (at Altenau) was a leady copper slag, smelted with iron and arsenical pyrites.

	Ni,Co	Cu	Fe	Pb	As	Sb	S
Speiss...	26.77	19.85	15.82	12.14	12.15	10.01	4.57
Matte...	6.10	37.24	20.84	16.10	.....	0.47	19.25

The speiss was roasted, then resmelted with heavy spar, arsenical pyrites, copper-refinery slags, and slag from lead-matting giving:

	Ni	Co	Cu	Fe	Pb	As	Sb	S
Speiss...	35.13	10.70	17.18	8.41	6.59	18.65	10.82	2.16
Matte..	4.37	.....	37.45	12.68	22.81	tr.	tr.	24.48

Smalt is a highly siliceous potash glass colored blue with cobalt monoxide (from 1.95 to 18 per cent.). In the commercial manufacture cobalt ore is usually partially roasted, leaving enough arsenic to form speiss with the iron, nickel, copper and part of the cobalt and melted with washed pulverized silica and potash. Allowing a small quantity of cobalt to enter the speiss insures the absence of nickel from the smalt. The glass after prolonged fusion and stirring is finally poured into water, stamped, jigged to free it from entrained speiss and sieved.

Typical analyses according to SCHNABEL are:

	Coarse color	Second grade pigment	Coarse pale color
SiO <sub>2</sub> .. . . .	70.86	66.20	72.12
Al <sub>2</sub> O <sub>3</sub> .. . . .	0.43	0.64	1.80
FeO .. . . .	0.24	1.36	1.40
CaO .. . . .	.....	.....	1.92
CoO .. . . .	6.49	6.75	1.95
K <sub>2</sub> O .. . . .	21.41	16.31	20.04
Ni .. . . .	.....	.....	tr
As <sub>2</sub> O <sub>3</sub> .. . . .	tr	.....	0.078
CO <sub>2</sub> .. . . .	.....	0.25	0.46
H <sub>2</sub> O .. . . .	0.57	0.67	tr
	100.00	92.18	99.768

## MERCURY SMELTING

The treatment of quicksilver ores as practiced at the Oceanic Mine, Cambria, Calif., probably represents the best practice in the United States. This was described by C. A. HEBERLEIN (February meeting, 1915, A.I.M.E.), the following being an abstract of his paper. Wet ores are first concentrated and then treated in the Scott furnace, but the dry ores are charged direct. The ore is crushed at the mine to about  $1\frac{1}{2}$  in. diameter and brought to the plant by bucket tramway. The wet ore goes to a  $3\frac{1}{2}$  ft. Huntington mill provided with a 16-mesh screen. The undersize goes direct to a DEISTER table.

The gangue is more friable than the mineral and little sliming takes place. The feed contains about 0.3 per cent. Hg, and the concentrates about 5 per cent. Hg. The extraction is about 80 per cent. and concentration about 20:1. Costs are about 50 cts. per ton. Flotation has been tried on quicksilver ores but the process does not appear to be a commercial one as fine grinding costs about as much as the ordinary furnace process; and the oil sticking to the concentrate would distil over with the mercury, making the "soot" more difficult to treat.

The furnace is a 50-ton Scott furnace. The sealing apparatus is said to be highly effective. (A cut of this is given in the *Transactions* of the A.I.M.E., to which reference is made.) Fuel consumption is said to be 15 cords of wood per month, treating 750 tons of ore and producing about 100 flasks of quicksilver.

At the plant the condensers after the first one are no longer built of brick, but of redwood, connected by a cast-iron down-take with the furnace. The gases entering the condenser are hardly over  $250^{\circ}\text{C}$ . and as drawn off from it are about  $170^{\circ}\text{C}$ . These wooden condensers are square wooden boxes of tongue and groove construction. The gases are admitted at the top and drawn off at the bottom. All baffling, etc., is unnecessary. The tops of the wooden condensers are water cooled. About 1000 gal. of water run out daily from the second (first red-wood) condenser, representing the condensed moisture from the ore. This is highly acid and carries quicksilver in solution.

A 50-ton Scott furnace with all accessories costs about \$25,000 on a pre-war price basis. Direct smelting costs about 47 cts per ton.

No analyses of soot is given, but some taken from European practice are appended.

**MERCURY SMELTING****ANALYSES OF MERCURY SOOT FROM DISTILLATION FURNACES<sup>1</sup>**

Mercury.....	56.30	6.42	3.12
Mercuric sulphide.....	0.70	2.20	31.10
Mercuric sulphate.....	18.99	13.07	10.80
Mercurous chloride.....	2.20	1.80	.....
Sulphuric acid.....	1.10	4.80	.....
Magnesia.....	.....	1.10	.....
Lime.....	0.76	1.20	.....
Ferric oxide and alumina....	tr.	0.80	.....
Calcium sulphate....	1.04	6.30	.....
Basic ferric sulphate....	3.24	0.40	.....
Soot and tar.....	33.9	29.40	24.80
Water.....	4.60	26.50	10.30
Ore residues.....	11.41	3.80	2.20
Magnesium sulphate....	.....	.....	7.50
Sodium sulphate.....	.....	.....	1.24
Ammonium sulphate....	.....	.....	0.54
Ferrous sulphate....	.....	.....	6.02

The mercury is extracted from these residues by pressing, followed by retorting.

<sup>1</sup> SCHNABEL, "Handbook of Metallurgy," Vol. II. The Macmillan Co.

**Cost of Scott Furnace<sup>1</sup>**

The latest Scott furnace erected at the Mariscal mine in Texas, cost \$19,536, without housing and without condenser system, or less than \$400 per ton of daily capacity.

**Condensers at Oakes Plant<sup>1</sup>**

At the plant of F. W. Oakes, Jr., Terlingua district, Texas, two Cyclone settlers are used in tandem between the furnace and the condensers. These are insulated with 4 in. of Diatomite. The condensers are made of 18-gage monel metal and have worked well on cinnabar ores, but they will fail if chlorides are present in the material sent to the furnace.

<sup>1</sup> Quicksilver Industry in 1929, Duschak and Maier, *Trans. A.I.M.E.*, February, 1930, meeting.

## COPPER REFINING

ELIMINATION OF IMPURITIES IN REVERBERATORY REFINING OF COPPER<sup>1</sup>

	Cu	Fe	S	Pb	Bi	Sb
Before	98.283	0.062	0.2576	0.5382	0.0045	0.1853
After	.....	.....	.....	0.1100	0.0101	0.1527
Before	.....	0.036	0.086	0.029	0.017	0.032
After	99.399	0.004	0.0009	0.006	0.007	0.007
Before	.....	0.013	0.088	0.007	0.001	0.129
After	99.475	0.004	0.006	0.004	0.003	0.017

	As	Te	Se	Ni	Ag ounces	Au ounces
Before	0.1709	0.0054	Trace	0.0473	59.91	0.276
After	0.1502	0.0195	Trace	0.0539	61.7	0.27
Before	0.054	0.014	0.010	0.008	.....	.....
After	0.010	0.003	0.009	0.009	68.17	0.204
After	0.067	0.006	0.005	0.009	.....	.....
After	0.045	0.003	0.007	0.013	39.893	0.251

<sup>1</sup> Private notes.

## ELIMINATION OF IMPURITIES IN CUPOLA (BLACK COPPER SMELTING)

	Cu	Pb	Bi	Sb	As	Te & Se
Refining furnace slag...	44.47	0.594	0.002	0.2044	0.049	0.0026
Cupola slag.....	.....	0.26	0.0	0.0317	0.0033	0.0
Black copper.....	97.7	0.78	0.035	0.0238	0.052	0.0095
Per cent. elimination...	.....	4.4	0.0	13.5	6.0	0.0

In refining blister copper to anodes KELLER gives the following table of relative slaggability of the various metals:

Cu	Pb	Bi	Sb	As	Te, Se
1	52.1	1.07	5.90	5.07	0.84

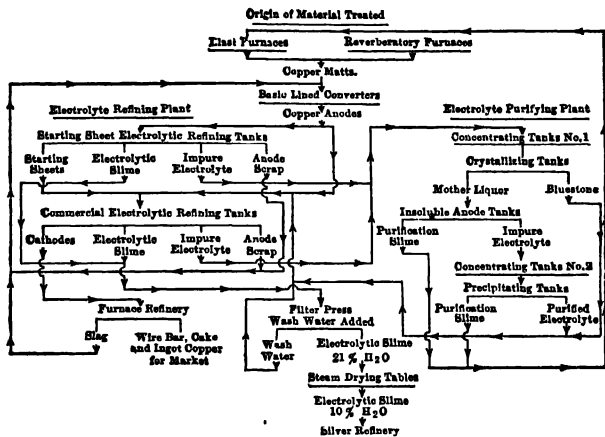
This omits volatilization losses, which would be higher for the last four elements than for the first two ("Mineral Industry," 1901, p. 248).

In the converter, KELLER figures that the percentage eliminations of impurities are as follows:

Per cent.	S	Fe	Zn	Co	Ni	Pb	Bi	Sb	As	Te
	99	99	99	99	37	96	97	71	81	40

These may serve as the slaggability ratios in the old acid-lined converters.

**Reduction of  $\text{Cu}_2\text{O}$  by  $\text{CO}$ .**—Less than 0.1 mm. of  $\text{CO}$  in an atmosphere of otherwise pure  $\text{CO}_2$  will reduce solid  $\text{Cu}_2\text{O}$  below  $1064^\circ\text{C}$ . This is important in the bright annealing of copper.



Flow sheet of Great Falls Electrolytic Plant<sup>1</sup>

### ELECTROLYTIC REFINING CURRENT LOSSES<sup>2</sup>

320 tanks—22 anodes, 22 cathodes per tank—90 per cent. amp. eff.—2-day cathodes.

	Volts per tank	Volts per 320 tanks	Percentage distribution
Voltage drop—bus bar to anode.	0.044	14.08	7.40
Voltage drop through electrolyte	0.495	158.72	83.36
Voltage drop—cathode to bus bar	0.055	17.60	9.24

<sup>1</sup> W. T. BURNS, *Trans. A. I. M. E.*, August, 1913.

<sup>2</sup> R. S. McCaffery, in the "Wisconsin Engineer."

**Converter and Furnace-refined Copper Anodes<sup>1</sup>****COMPARISON OF CONVERTER AND REFINED ANODES CAST IN THE SAME MOULDS**

	Converter anodes	Refined anodes
Number of days covered by test. . . . .	50.0	50.0
Number of refining tanks employed . . . . .	48.0	48.0
<b>Average analyses of anodes:</b>		
Per cent. Cu. . . . .	98.91	99.27
Per cent. As + Sb. . . . .	0.072	0.071
Ounces Ag per ton. . . . .	59.09	61.14
Ounces Au per ton. . . . .	0.200	0.219
<b>Average analyses of electrolyte:</b>		
Specific gravity. . . . .	1.20	1.20
Grams per liter Cu. . . . .	43.5	43.5
Grams per liter free acid. . . . .	160.0	160.0
Grams per liter As. . . . .	11.97	11.97
Grams per liter Sb. . . . .	0.49	0.49
Grams per liter Fe. . . . .	10.09	10.09
Grams per liter Cl. . . . .	0.045	0.045
<b>Average temperature of electrolyte:</b>		
Inlet of 8-tank cascade, C°. . . . .	58.0	58.0
Outlet of 8-tank cascade, C°. . . . .	54.0	54.0
Rate of circulation of electrolyte, gal per min. . . . .	6.0	6.0
Number of anodes per tank . . . . .	20.0	20.0
Number of cathodes per tank . . . . .	20.0	20.0
Average weight per new anode, lb. . . . .	525.0	632.0
Average thickness per new anode, in. . . . .	3.0	3.0
Distance, center of anode to center of cathode, in. . . . .	2.87	2.87
Active cathode surface per tank, sq. ft. . . . .	252.0	252.0
Average amperes per tank. . . . .	8,387.0	8,387.0
Average volts for 48 tanks. . . . .	27.21	28.53
Average volts per tank. . . . .	0.567	0.594
Average kilowatts for 48 tanks. . . . .	228.2	239.3
Total copper deposited, lb. . . . .	1,103,749	1,148,749
Average age of cathodes drawn. . . . .	2½	2½
Average ampere efficiency of deposit, per cent. . . . .	88.3	91.9
Average amperes per sq. ft. cathode surface. . . . .	33.3	33.3
Average lb. copper deposited per kilowatt-hour. . . . .	4.03	4.00
Average oz. per ton silver in cathodes. . . . .	1.25	0.95
Average per cent. As + Sb in cathodes. . . . .	0.0043	0.0043
Average per cent. anode scrap. . . . .	8.00	5.30
<b>Analyses of silver slime:</b>		
Per cent. Cu. . . . .	40.3	18.80
Ounces Ag per ton. . . . .	6,755.00	14,079.0
Ounces Au per ton. . . . .	18.34	38.45

The chief disadvantages of converter anodes are: lower grade slimes; higher losses of silver in the cathodes; and higher percentage of anode scrap. However, W. T. BURNS states that the losses due to these factors are not equal to half the cost of reverberatory refining.

**Starting-sheet Tank Electrolyte**

Specific gravity . . . . .	1.175
Free H <sub>2</sub> SO <sub>4</sub> , grams per liter . . . . .	120.0
Cu, grams per liter . . . . .	40.0
As, grams per liter . . . . .	5.0
Sb, grams per liter . . . . .	0.4
Fe, grams per liter . . . . .	4.5
Cl, grams per liter. . . . .	0.04

<sup>1</sup> *Trans. A.I.M.E.*, August, 1913.

### Elimination of Impurities in Electrolytic Refining

According to KELLER's figures about 99.92 per cent. of the copper in the anode goes into solution, the remainder to the slime; from 61 to 78 per cent. of the bismuth goes into the slimes, 30 to 60 per cent. of the antimony (according to conditions worked under), 23 to 38 per cent. of the arsenic; while the silver, gold, selenium, tellurium and lead are quantitatively slimed ("Mineral Industry," 1898, Vol. VII, p. 239). Nickel is slimed if it is present as oxide in the anode copper; dissolved if present as metal. Cobalt, zinc, manganese and iron go into solution.

### Work in Insoluble-anode Tanks<sup>1</sup>

#### REMOVAL OF COPPER, ARSENIC AND ANTIMONY FROM ELECTROLYTE IN INSOLUBLE-ANODE TANKS

(Circulation, 4 liters per minute. Lead anodes, copper cathodes, 9000 amp., 31.8 amp. per square foot)

	Grams per liter					Volts per tank	Temperature, C.
	Acid	Cu	Fe	As	Sb		
Inlet tank No. 1.	144	37.060	6.242	3.200	0.463	.....	17
Outlet tank No. 1	184	7.376	6.813	2.240	0.260	2.22	42
Outlet tank No. 2.	194	0.504	7.364	0.406	0.061	2.25	57
Outlet tank No. 3.	208	0.088	7.701	0.056	0.038	2.25	61
Outlet tank No. 4	216	0.048	7.915	0.028	0.028	2.25	65

### CORRECTED ANALYSES<sup>1</sup>

	Grams per liter					Percentage elimination of original amounts			Ampere efficiency, per cent.
	Acid	Cu	Fe	As	Sb	Cu	As	Sb	
Inlet tank No. 1.	144	37.060	6.242	3.200	0.4630	....	....	....	.....
Outlet tank No. 1	169	6.760	6.242	2.050	0.2380	81.8	35.9	48.7	71.70
Outlet tank No. 2	165	0.427	6.242	0.339	0.0517	17.1	53.5	40.2	19.50
Outlet tank No. 3	169	0.071	6.242	0.045	0.0308	0.9	9.2	4.7	1.68
Outlet tank No. 4	170	0.038	6.242	0.022	0.0220	0.1	0.7	1.7	0.15
Total and average	....	...	.....	.....	.....	99.9	99.3	95.3	23.26

<sup>1</sup> Calculated to the same value for iron, which is not affected in the insoluble-anode tanks.

See p. 761 for some notes on lead, duriron and tantiron as insoluble anodes.

<sup>1</sup> W. T. BURNS, *Trans. A. I. M. E.*, August, 1915.

## COPPER REFINING—ANALYSES OF TYPICAL PRODUCTS

	Converter anodes, <sup>1</sup> per cent.	Electrolyte, <sup>1</sup> per cent.	Wire bar, <sup>1</sup> per cent.	Electrolytic slime per cent.	Electrolyte <sup>2</sup>	Refining-fur- nace anodes <sup>2</sup>	Slimes flue dust <sup>3</sup>	Casting cop- per	Blue stone	Blue stone	Slimes flue dust <sup>4</sup>	Anode fur- nace flue dust	Wire bar flue dust	Crude nickel
Copper.....	99.1300	3.280	99.9500	43.3400	4.51	99.25	2.10	99.34	24.89	25.07	1.70	11.10	31.49	None
Arsenic.....	0.1183	0.500	0.0016	3.0300	0.250	0.060	4.85	0.4237			5.51			0.0023
Antimony.....	0.0534	0.041	0.0015	3.4600	0.0451	0.022	15.36	0.1092			17.04			0.0048
Nickel.....	0.0420	0.377	0.0006	0.0800	0.85	0.050		0.0795	0.263	0.166				19.27
Cobalt.....	0.0018	0.016	Trace	0.0060										
Bismuth.....	0.0038	0.021	0.0004	0.1100	0.0033	0.0030		0.0136						
Iron.....	0.0110	0.600	0.0006	0.3640	0.1456	0.058		0.0026	0.245	0.170		3.20	2.80	0.0140
Silver.....	0.1371	None	0.0030	17.1870	None	0.103	2.460	Trace			3.20	0.20	0.01	
Gold.....	0.0008	None	Trace	0.1200	None	0.0270	0.003				0.015	0.01	Trace	
Selenium.....	0.0090	None		1.2000	None	0.048	7.84				19.52			
Tellurium.....	0.0170	None		2.1000	None	0.038	1.32				1.38			
Lead.....	0.0065	Trace	Trace	0.7600	0.053	0.053								
Zinc.....	0.0035	0.418	0.0001	0.0900	0.0226	0.0250								0.0574
Sulphur.....	0.2610		0.0025	13.2100	0.004	0.004						7.39	4.19	0.2725
Oxygen.....			0.0350			0.100								
Silica.....				0.1770										
Chlorine.....		0.0040		0.0260	0.003									
Carbon.....				0.5900										
Platinum.....				0.000166										
Free sulphuric acid.....		13.0300												
Specific gravity.....		1.220			1.260							29.48	32.61	

<sup>1</sup> First four columns from WILLIS T. BURNS' "The Great Falls Electrolytic Refinery," Trans. A.I.M.E., Aug., 1913.<sup>2</sup> Eastern practice. <sup>3</sup> Near slimes furnace. <sup>4</sup> Distant from slimes furnace.



**Slime from Insoluble-anode Tanks**

(Treating electrolyte direct from tank room)

Moisture, per cent.	10 0	As, per cent. ....	10.3
Cu, per cent. ....	55 1	Sb, per cent. ....	2.5
SiO <sub>2</sub> , per cent. ....	1 1	Ni, per cent. ....	3.05
FeO, per cent. ....	0 4	Zn, per cent. ...	0.32
Al <sub>2</sub> O <sub>3</sub> , per cent. ....	0 4	Ag, oz. per ton..	3.4
CaO, per cent. ....	0 3	Au, oz. per ton..	0.02
S, per cent. ....	4 1		

Better results are secured from the insoluble-anode tanks at Great Falls, when the electrolyte from the tank room is boiled until it reaches a specific gravity of 48°Bé. It is then crystallized for 4 days, when the mother liquor then analyzes: acid, 475; Cu, 17.4; As, 20.2; Sb, 1.1; and Fe, 15.2 grams per liter. This is then electrolyzed to remove Cu, As and Sb.

**Analysis of Insoluble-anode Tank Slime**

(Treating mother liquor from crystallizing tanks)

Moisture, per cent	9.66	As, per cent. ...	21.48
Cu, per cent. .	46 30	Sb, per cent. ..	2 28
SiO <sub>2</sub> , per cent. ....	0.38	Ni, per cent. ....	0 35
FeO, per cent. ....	1 66	Zn, per cent. ..	0 32
Al <sub>2</sub> O <sub>3</sub> , per cent. ...	0 4	Ag, oz. per ton .	3 61
CaO, per cent. ...	1 08	Au, oz. per ton..	0.03
S, per cent. ....	5 02		

**Materials for Insoluble Anodes**

The usual materials for insoluble anodes are platinum, carbon, iron and hard lead, according to the nature of the electrolyte. Fused magnetite anodes are also being used, notably at Chuqucamata, Chile, but they are extremely expensive and very brittle. However, when the anodes do not have to be handled often, *i.e.*, are not subject to chance of breakage by carelessness, and can be guarded from sudden large changes of temperature, they are unquestionably the finest anodes obtainable. In ordinary copper tank-room practice hard-lead anodes are usually used in the insoluble-anode tanks. Herewith follow some notes, not hitherto published, furnished by F. R. PYNE, superintendent of the Raritan Copper Works at Perth Amby N.J., giving parallel tests on hard lead, duriron, and tantiron electrodes, using them as anodes in various electrolytes. The current density was about 20 amp. per square foot. In a 12 per cent. sulphuric-acid solution the tantiron lost 0.94 per cent. in 24 hours, the duriron lost 7.30 per cent. in 42 hours and the hard lead, 0.69 per cent. in 30 hours. In regular tank-house electrolyte of approximately 3 per cent. copper, 10 per cent. sulphuric acid, the tantiron lost 1.88 per cent. in 48 hours, the duriron 10 per cent. in 60 hours, the hard lead, 0.44 per cent. in 36 hours, and on another test in

## 762 METALLURGISTS AND CHEMISTS' HANDBOOK

the same solution the hard lead showed a loss of 1.71 per cent. in 48 hours. Tests made by the New England Manufacturing Co. in nitric acid electrolyte were as follows: The current used was 3 amp. per sq. in., 18 sq. in. of tantiron in 1.39 sp. gr. nitric acid lost 0.480 grams in 5 hours; 3 sq. in. of duriron lost 0.0036 grams in 6 hours in nitric acid of the same strength. Duriron anodes have also been used in the Chuquicamata electrolytic plant of the Chile Exploration Co. Regarding this, C. A. ROSE says in the *Engineering and Mining Journal* of Feb. 19, 1916: "While this material is not entirely unacted upon when used as an anode in copper-sulphate solution, from 15 to 20 times its weight of copper can be deposited before it is entirely corroded away. Duriron anodes have an advantage over magnetite in their mechanical strength, but they have a much higher over-voltage, which is a decided disadvantage. About 15 per cent. more electrical energy is required with duriron than with magnetite anodes for the deposition of the same quantity of copper."

As against a deposit of 8 to 8.5 lb. of copper per kilowatt-hour using the multiple process and 10.5 to 11.5 per kilowatt-hour when using the series process, ordinarily only about 1 lb. per kilowatt-hour is obtained with insoluble anodes.

### COMPARISON OF SERIES AND MULTIPLE REFINING

	Multiple	Cast-series
Ampere efficiency . . . . .	90 0	68 0
Volts per tank . . . . .	0 3	18.0
Anodes per tank . . . . .	28 0	120.0
Cathodes per tank . . . . .	29.0	120.0
Amp. per square foot . . . . .	18.0	16.0
Daily deposit per tank . . . . .	204 0	2040.0
Lb. Cu per kilowatt-hour . . . . .	7.79	11.79

### RESISTANCE OF ELECTROLYTES, COPPER REFINING<sup>1</sup>

Strength solution, per cent	CuSO <sub>4</sub>		FeSO <sub>4</sub>		H <sub>2</sub> SO <sub>4</sub>	
	Ohms per cc.	Ohms per cu. in.	Ohms per cc.	Ohms per cu. in.	Ohms per cc.	Ohms per cu. in.
2 5	92	37	...	...	...	...
5 0	53	21	...	...	4.8	1 9
7.5	...	...	65	26	...	...
10.0	31	12	...	...	2.5	1.0
15.0	24	10	34	14	1.8	0.7
17 5	22	9	...	...	...	...
20 0	...	...	...	...	1 5	0.6
25.0	...	...	...	...	1.4	0.56
30.0	...	...	25	10	1 37	0.55

<sup>1</sup>J. W. RICHARDS, "Metallurgical Calculations." See also the tables on pp. 182-192

The experience of New Cornelia Copper Co. using  $3\frac{1}{2}$  per cent. antimonial-lead anodes<sup>1</sup> has been very satisfactory. In one year the anodes had not become appreciably oxidized.<sup>1</sup>

For large scale work with insoluble anodes the choice lies between graphite (particularly for chlorides), hard lead, or some silicon alloy (tantiron, duriron, corrosiron, or more particularly, the Fink cuprosilicon anode).

The cuprosilicon anode has replaced fused magnetite at Chuquicamata and consists of Si, 15 to 25 per cent., Mn, 2 to 15 per cent.; Pb, 0.5 to 10 per cent.; a little Pb; a little Fe, and the remainder Cu (U. S. Pats. 1441567 and 1441568). It is noteworthy for its low overvoltage. Other silicides may also be used.

Cobalt silicide is the most insoluble of these silicides.

Duriron anodes precipitate gold out of solution. Nichrome anodes are preferable.

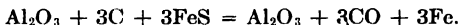
### Aluminous Ore Refining

**Bayer Process.**—An extremely high grade bauxite is required,  $\text{SiO}_2$  not over 3 per cent. The ore is mixed after grinding with strong soda liquor and heated for 8 hr. in an autoclave. The solution is diluted to 1.20 sp. gr. and the alumina precipitated in large tanks by agitation and the addition of a little aluminum hydrate. In a modification of this process the ore is ground and mixed with sodium carbonate and roasted at about  $1000^\circ\text{C}$ . and the sodium aluminate leached out.

**Berger Process.**—China clay (kaolin) is broken into lumps of 6 to 7 lb. each and roasted with three times its weight of iron pyrites and some magnesium chloride at  $400$  to  $500^\circ\text{C}$ . passing a current of chlorine gas through the mixture. Aluminum chloride is said to distill over leaving silica, magnesia and ferrous oxide behind. It is difficult to see how the formation of volatile ferric chloride can be prevented, though the process is said to have some use in Germany.

**Blanc Process.**—The process treats leucite rock of about 23 per cent.  $\text{Al}_2\text{O}_3$ ; 55 per cent.  $\text{SiO}_2$ ; and 18 per cent.  $\text{K}_2\text{O}$ . This is crushed to about 1 mm. size and treated with hydrochloric acid, dissolving the potassium and aluminum. The former largely precipitates on cooling. After removal of the KCl, the aluminum chloride is precipitated by passing HCl gas into the solution. The aluminum chloride is then heated to  $350^\circ\text{C}$ . in iron tanks, regenerating hydrochloric acid and giving alumina.

**Haglund Process.**—Aluminous ore is mixed with anthracite and pyrites. On fusing in a smothered arc or resistance furnace, the iron, silicon, and titanium are reduced and tapped off. The main reaction is:



<sup>1</sup> TOBELMANN and POTTER, "Leaching by New Cornelia Copper Co.," *Bull. A. I. M. E.*, May, 1919, p. 479.

The fused aluminum sulphide acts as a solvent to hold the alumina in solution at 1100°C. The slag is then cooled, crushed and leached with hot water and steam. The material is then classified and concentrated, to obtain  $\text{Al}_2\text{O}_3$  and  $\text{Al}(\text{OH})_3$ , the concentrate finally being calcined, after washing with dilute  $\text{H}_2\text{SO}_4$  to remove  $\text{TiO}_2$ .

**Hall Process.**—Bauxite is ground and intimately mixed with ground coal. The mixture is sintered at about 1000°C., cooled and a further quantity of coke introduced. The mixture is then smelted in a Soderberg furnace at about 2500°C. Ferro-silicon and ferro-titanium sink to the bottom of the bath and are tapped off. The purified alumina is blown off by steam and air pressure from the top of the furnace into an iron chamber where it condenses in flocculent particles. After washing with dilute sulphuric acid to remove titanium the material is filtered and dried. Bauxites of high silica content can be handled by this process.

**Pedersen Process.**—This process uses high-iron bauxites, smelting out the iron and silicon in an electric furnace and leaching the rich aluminous slag with hot, dilute, sodium carbonate.

**Serpek Process.**—Bauxite is mixed with crushed carbon and heated in an electric resistance furnace with air.



The aluminum nitride is then digested in an autoclave under steam pressure:



or else the AlN is digested with soda solution, forming sodium aluminate which is then treated as in the Bayer process.

**Heat Treatment of Aluminum-silicon Alloys** ("195" alloy, 25 S, Special 17 S, 51 S, LAUTAL).—The heat-treatment effects in aluminum-silicon alloys may be considered as due to one or more of these structural changes: solution; precipitation; spheroidizing; grain growth.

**Solution.**—Strength and hardness may be increased very materially, in some cases by well over 50 per cent., by quenching from about 565°C. as compared with cooling slowly. This hardening is accompanied by decreased plasticity and usually by decreased elongation. From the known constitution of the system, it is to be expected that the magnitude of the solution effect will vary with the quenching temperature up to the melting point of the eutectic (577°C.), increasing as the temperature is increased.

Results analogous to those of a solution heat treatment can be produced by quenching castings shortly after solidification.

**Precipitation.**—Aging at room temperature has substantially no effect on the tensile properties or hardness of aluminum-silicon alloys, either as cast or after a solution heat treatment. Aging at elevated temperatures (150°–400°C.) after a solution heat treatment at 570°C. may increase hardness by about 15 to 20 per cent. This hardening seems to be accompanied by decreased plasticity and, usually, ductility.

**Spheroidizing.**—Spheroidizing and growth of the silicon particles are very marked on heating at about  $565^{\circ}\text{C}.$ , but also occur at lower temperatures. They result in decreased hardness and strength and increased plasticity, usually with increased ductility. These effects increase with the temperature and time of heat treatment.

**Conclusions.**—In general, treatment for a short time at temperatures around  $565^{\circ}\text{C}.$ , followed by quenching, favors the predominance of the solution effect, while a long-time treatment favors the predominance of the spheroidizing effect. Thus the strength and hardness of castings may be increased by short heat treatments but reduced by long heat treatments. The plasticity of a cast alloy is apt to be decreased by a short treatment, due to the solution effect, but is increased as the time of treatment is prolonged, due to the spheroidizing effect. Elongation is a complex property depending on both strength and plasticity. It may be increased by a solution heat treatment which at the same times decreases plasticity. It may be further increased when the spheroidizing effect increases plasticity.

### Electrolytic Production of Various Metals

**Aluminum**—from fused cryolite bath containing  $\text{Al}_2\text{O}_3$  in solution (cryolite 36 per cent.;  $\text{AlF}_3$  44;  $\text{CaF}_2$  20). The specific gravity of a saturated solution of  $\text{Al}_2\text{O}_3$  in cryolite is 2.35, that of molten aluminum is 2.54. The bath must be fluid at  $900^{\circ}$  to  $950^{\circ}\text{C}.$  Cryolite melts at  $1000^{\circ}\text{C}.$ , but with 10 per cent.  $\text{Al}_2\text{O}_3$  present it is  $930^{\circ}\text{C}.$ , and with 20 per cent.  $880^{\circ}\text{C}.$ ; 25 per cent. saturates the solution. The current density is about 700 amp. per square foot of cathode section, potential (theoretical, 2.8 volts) 7.5–8.5 volts. Anodes are carbon blocks, cathode the carbon lining of the furnace. Power consumption 1400 e.h.p. per metric ton of metal per 24 hours. Also prepared by electrolyzing a double sulphide of aluminum and sodium. Potential about 5 volts. The alumina for electrolysis should carry a minimum of 98 per cent.  $\text{Al}_2\text{O}_3$ .

### SOME TYPICAL BAUXITES<sup>1</sup>

	New South Wales	Italian	French	French	German
$\text{Al}_2\text{O}_3$ ....	42 20	47.44–57.00	78.10	43.20	55.61
$\text{Fe}_2\text{O}_3$ ...	28.91	25.98–36.77	1.02	7.25	7.17
$\text{SiO}_2$ ....	0.16	2.33– 4.06	5.78	34.40	4.42
$\text{TiO}_2$ ....	4.75	1.17– 2.			
$\text{CaO}$ ....	0.28				
$\text{MgO}$ ...	0.37				
$\text{KNaO}$ ..	0.17				
Volatile..	23.45		15.10 •	15.15	32.33

<sup>1</sup> SCHNABEL, "Handbook of Metallurgy" The Macmillan Co.

**Refining Aluminum.**—Aluminum can be refined in a fused salt bath using an anode of fused impure aluminum. The electrolyte is aluminum fluoride containing enough barium fluoride so that the specific gravity of the bath is less than the impure aluminum anode and greater than that of c.p. aluminum. The cathodes are graphite and after action begins the refined aluminum rises and floats on the bath.

**Antimony.**—May be recovered by electrolysis from the sulph-antimonite. The anodes are lead plates, the cathodes and tanks are iron. Current density is 10 to 15 amp. per square foot at start, later 4 to 5 amp. per square foot. The voltage is about 2. The metal is always contaminated with iron when produced in this way. Betts also proposes electrolysis of the fluoride in solution carrying an excess of hydrofluoric acid.

**Beryllium.**—From the fused double fluoride of sodium and beryllium.

**Bismuth.**—Is refined electrolytically in  $\text{BiCl}_3$  solution carrying an excess of free hydrochloric acid. Current density, 15–30 amp. per square foot. Anodes, argentiferous and auriferous bismuth; cathodes, pure bismuth; porcelain tanks.

**Cadmium.**—Obtained by the electrolysis of  $\text{CdCl}_2$  or  $\text{CdSO}_4$  solutions. Current density, 6 to 15 amp. per square foot; c.m.f., 0.045 volts. Cathodes are cadmium sheets, anodes are of crude cadmium.

**Calcium.**—From fused calcium chloride or iodide. Current density must exceed 500,000 amp. per square meter. Electrolyte near cathode must be at lowest possible temperature. Cell resistance, 12 volts.

**Cerium.**—From the fused chloride, which is traversed by an alternating current to keep it fused and decomposed by direct current.

**Chromium.**—According to BORCHERS, may be produced by electrolysis of a  $\text{CrCl}_2$  solution containing 13–14 oz. of chromium per gallon. The anodes are carbon, the cathodes platinum foil. The current density must be from 85 to 170 amp. per square foot. At 70 amp. per square foot the metal contains perceptible amounts of  $\text{CrO}$ , and with 8 amp. per square foot, only  $\text{CrO}$  is deposited. The temperature must not exceed  $122^\circ\text{F}$ . G. GLASER has compiled the following table regarding the behavior of chromium during electrolysis:

Current density, amp. per sq. ft.	Deposit	Current efficiency
8.36	Chromo-chromic oxide.....	.....
16.7 <sub>a</sub>	At first metal, then chromo-chromic oxide.....	.....
33.4	Metal, mixed with chromo-chromic oxide.....	.....
41.7	Thin metallic layer, on which oxide afterward deposits.....	5.4
66.8	Metal, wth a small quantity of oxide.....	23.4
84.5	Pure metal.....	38.4
127.3	Pure metal, with a growth of crystals.....	38.0
169.0	Pure metal, for the most part crystallized.....	38.6

The effect of solution concentration was also studied:

Grams Cr per liter of solution	Deposit	Current efficiency
210	Metallic powder, mixed with chloride of chromium .....	
184	Same.....	
158	Pure metal.....	56.6
135	Pure metal.....	49.0
105	Pure metal.....	38.4
79	At first metal, then chromo-chromic oxide.....	
53	Chromo-chromic oxide and hydrogen.....	
26	Trace of chromo-chromic oxide, brisk evolution of hydrogen.....	

**Copper.**—Refined by the electrolysis of copper-sulphate solutions carrying free sulphuric acid, using copper cathodes and anodes. Current density about 12 to 15 amp. per square foot, e.m.f. 0.34 to 0.44 volt. Temperature of solution about 114°F. Ag, Au, Pb, Se, Te go quantitatively to the slime; Bi, As, and Sb, chiefly to the slime; Fe, Ni, Co into solution, except the nickel be present in the anode as NiO.

**Gold.**—From gold-chloride solution carrying 25–30 oz. of gold and 25–30 oz. free HCl (sp. gr. 1.19) per cubic foot. The anode is the unrefined gold, the cathode is a pure sheet. If anodes carry lead, some  $\text{H}_2\text{SO}_4$  is added. Current density about 100 amp. per square foot, potential 1 volt, temperature 60–70°C. Tanks—stone or porcelain. (WOHLWILL process.) Pt stays in the electrolyte, Ag slimes as chloride.

**Iron.**—May be obtained by electrolysis of the sulphate. Anodes are pig iron, the cathodes are pure metal. Current density about 110 amp. per square meter, electrolyte contains 10 per cent.  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  and 5 per cent.  $(\text{NH}_4)_2\text{SO}_4$ . Temperature carried at about 30°C. Voltage drop across tank about 0.3 to 0.9 volts. This, however, gives a metal carrying a trace of sulphur. While a chloride electrolyte is free from this objection, iron produced with such an electrolyte corrodes readily because of occluded chlorine. In either case there is a large amount of occluded hydrogen. (See also pp. 366 and 776.)

**Lead.**—Can be produced by electrolysis in a solution of lead fluosilicate carrying free hydrofluosilicic acid and a little gelatin. Anodes, base bullion; cathodes, pure lead sheets. Temperature of solution, about 87°F. cathode density, 10–12 amp. per square foot.; potential, about 0.3 volts; tank, wooden.

**Lithium.**—from fused mixtures of LiCl with an alkaline-earth chloride. From a solution of lithium chloride in pyridine. 20–30 amp. per square centimeter, 14 volts.

**Magnesium.**—From fused magnesium chloride, from fused K-Mg or Na-Mg chlorides. Current density, 1000 amp. per square meter; cell voltage, 1 to 8; anode, carbon in porcelain envelope. Do not raise temperature of bath much above melting point of the magnesium.

**Potassium.**—From fused mixtures of KCl with an alkaline-earth chloride. General process same as sodium.

**Silver.**—(MOEBIUS and THUM processes) recovered by electrolysis of a nitrate solution carrying about 0.1 per cent. free  $\text{HNO}_3$ , 5.0 per cent. Ag, and some copper. The cathode is either silver (MOEBIUS process), or carbon (THUM process). The anode is the doré. The current density is 30–40 amp. per square foot; the e.m.f. is 1.4–1.5 volts; the tanks are usually porcelain. The Cu in the anodes dissolves; Pt and Au stay in the slime.

SOLUBILITY OF SILVER CHLORIDE<sup>1</sup>

Salt	Strength of solution, per cent.	Temperature, deg. C.	Silver chloride dissolved per liter, grams	Silver per liter, grams
KCl.....	24.95	19.6	0.914	0.688
NaCl.....	25.96	19.6	1.270	0.956
$\text{NH}_4\text{Cl}$ .....	28.45	30	3.673	2.764
$\text{CaCl}_2$ .....	41.26	30	8.350	6.283
$\text{BaCl}_2$ .....	27.32	30	0.741	0.558
$\text{MgCl}_2$ .....	36.35	30	7.095	5.339
$\text{FeCl}_2$ .....	30.70	20	2.395	1.802
$\text{FeCl}_3$ .....	37.48	21.4	0.085	0.064
$\text{MnCl}_2$ .....	43.85	30	2.958	2.226
$\text{ZnCl}_2$ .....	53.34	30	0.215	0.162
$\text{CuCl}_2$ .....	44.48	30	0.833	0.627
$\text{PbCl}_2$ .....	0.99	30	.....	.....

<sup>1</sup> SCHNABEL'S "Handbook of Metallurgy," Vol. I. The Macmillan Co.

The above table is by H. C. LAHN and W. M. CURTIS. According to VOGEL and BERNHART, the solubilities in grams of silver chloride per liter of solution are as follows: KCl, 0.472; NaCl, 0.950;  $\text{NH}_4\text{Cl}$ , 1.575;  $\text{CaCl}_2$ , 0.930;  $\text{BaCl}_2$ , 0.143;  $\text{SrCl}_2$ , 0.884;  $\text{MgCl}_2$ , 1.710. They also state that it is insoluble in the chlorides of tin, mercury, copper, zinc, cadmium, nickel and cobalt. But some unpleasant experiences of my own convince me that it is highly soluble in a mixture of cuprous and cupric chlorides.

**Sodium.**—From fused sodium hydroxide—CASTNER process—Iron anode, carbon cathode. From fused sodium nitrate—DARLING'S process—Iron melting vessel serving as anode. Magnesia diaphragm, carbon cathode. Cell resistance 15 volts. From fused sodium chloride. Current density over 5000 amp. per square meter.

**Strontium.**—From fused strontium chloride. General conditions like those of calcium production.

**Tin.**—The electrolysis of tin commercially is confined to the detinning of old tin-plate, chiefly by the caustic-soda process. The cathodes are iron, the anodes are the tin scrap, packed in wooden baskets. Electrolyte contains about 9 per cent.  $\text{NaO}$ .



H, which is recausticized from time to time by  $\text{Ca(OH)}_2$ . The tank potential is about 1.5 volts, the current density 8–12 amp. per square foot and the temperature  $160^\circ\text{F.}$  and up. Alkaline sulpho-stannates have also been proposed as electrolytes.

The best electrolytic tin deposits are probably obtained from a bath of:

Sulphuric acid, 8.0 per cent.; cresolphénol sulphonic acid, 4.0 per cent. (made by heating phenol and cresol with concentrated sulphuric acid; and stannous tin, 3.0 per cent. Addition agent,  $\frac{1}{3}$ –3 lb. of glue and 8–16 lb. cresylic acid per ton of tin. (H. H. ALEXANDER, *Trans. A. I. M. E.*, February, 1924, meeting.) Current density, 8–10 amp. per sq. ft., temperature,  $95^\circ\text{F.}$

**Uranium.**—From fused uranium-sodium chloride; cell resistance, 8 to 10 volts.

**Zinc.**—The Brunner, Mond & Co. works at Winnington is said to operate as follows: The electrolyte is  $\text{ZnCl}_2$  with 0.08 to 0.12 per cent. free  $\text{HCl}$ , the cathodes are rotating zinc plates, and the anodes are carbon. The current density is 10 amp. per square foot and the e.m.f. of the cell is 3.3 to 3.8 volts. The apparatus is complicated, as there must be piping for carrying off the chlorine generated, which is then used for making bleaching-powder. The solution tends to become basic after prolonged electrolysis and additional acid must be added.

In the process as conducted by Keating at Bully Hill, Calif., lime is used to precipitate zinc hydroxide and calcium sulphate from the solution of the zinc sulphate. This precipitate is suspended in the zinc sulphate liquor of the electrolytic cell and as fast as sulphuric acid forms it is neutralized by the zinc hydrate.

In the Mammoth Copper Co.'s experiments at Palo Alto, Calif., a sponge-lead cathode is used, the sulphuric acid formed by electrolysis forming lead sulphate, which can be decomposed later by reversing the current. The material used is said to be the result of leaching the baghouse dusts with sulphuric acid.

**Anaconda Electrolytic Zinc Plant.**<sup>1</sup>—This plant leaches zinc ores with sulphuric acid and electrolyzes the zinc sulphate. The ore is roasted in McDougall furnaces with a temperature of  $600^\circ\text{C.}$  on the lower hearths, and not over  $550^\circ\text{C.}$  on the upper, so that much of the zinc is converted to zinc sulphate. It has been found that the zinc solubility is greatly increased if the raw concentrates are moistened with sulphuric acid before roasting. High hearth-temperatures decompose the sulphates.

Leaching is in two stages: (1) A neutral leach in which all of the calcine and half the acid is added; (2) an acid leach in which no calcine and the remaining acid is added. Sufficient iron must be present and oxidized by manganese dioxide in the neutral leach to precipitate all of the arsenic and antimony. The final neutralization of the acid is by means of crushed lime rock.

<sup>1</sup> *Trans. A. I. M. E.*, February meeting, 1921.

Copper and cadmium are thrown down by excess of zinc dust. Cobalt may be thrown down with manganese by the addition of permanganate, or it may be precipitated direct by beta-naphthol and sodium nitrite, also by zinc dust from the neutral solution in the presence of ferric iron, copper and arsenic. These impurities must be eliminated almost completely.

The electrolytic cells are wood-lead lined 10 ft. 3 in. long  $\times$  2 ft. 10 in. wide  $\times$  5 ft. deep. The cathodes are aluminum 2 ft.  $\times$  3 ft. 6 in.  $\times$   $\frac{3}{16}$  in. thick. Three feet is submerged. Anode to cathode space is  $1\frac{3}{4}$  in. The drop across the cell is 3.8 volts and the current density is about 30 amp. per sq. ft.

The electrolyte from the last cell in cascade carries about  $2\frac{1}{2}$  per cent. Zn and  $11\frac{1}{2}$  per cent.  $H_2SO_4$ . Six cells are in cascade. The cathodes are of aluminum, slightly roughened. The anodes are lead. Glue is added in the proportion of 1 to  $1\frac{1}{2}$  oz. per ton of metal produced.

Copper, if not over 10 mg. per liter, appears to have no injurious effect. If above that, holes are eaten through the cathodes. Antimony is injurious even if only 1 part per 1,000,000 of electrolyte, as is also arsenic. Cadmium injures the grade of the zinc if over 20 mg. per liter of solution.

**Tainton-Pring Process as Used at Kellogg, Idaho.** (Sullivan Mining Co.).—The process is characterized by high acid and high current density as compared with low current density and low acid which are standard at Great Falls and Trail. The zinc concentrates are roasted at comparatively high temperature giving rise to high percentage of zinc ferrate. A magnetic separator divides the zinc oxide from the ferrate. The latter, which is soluble with difficulty in sulphuric acid solutions, is treated with the high acid (280 grams per liter) spent electrolyte from the cells. As the reaction slows down the final neutralization is carried out with the oxide portion of the roasted blende. The pulp is then filtered in Burt filters and the solution agitated with zinc dust. This precipitates copper, cobalt, and cadmium, after which the solution is filtered in presses and passes on to the electrolytic cells. The current density is 100 to 120 amp. per sq. ft., voltage 3.5. Lead anodes and aluminum cathodes are used. An electric furnace melts the stripped cathode sheets. The cast slabs analyze 99.99 per cent. Zn.

A unique plant produces the electrolytic lead. The cell is of the diaphragm type, with graphite anodes, steel cathodes and using the chloride solution. The lead is deposited on the rotating steel cathodes as a spongy mass which is continuously removed. The chlorine leaving the anode compartment passes into a suspension of lime and the chloride solution produced is fed into the tank holding the lead-rich electrolyte which has passed over fresh roasted ore. Soluble sulphates are precipitated as calcium sulphate.

**Anodes for Zinc Deposition.**—According to U. C. TAINTON (*Proc. A. I. M. E.*, February meeting, 1929), lead-silver alloys

containing about 1 per cent. of silver are superior to pure lead anodes in the electrolytic deposition of zinc. The zinc produced is purer, the manganese dioxide is nearly free from lead, and a closer spacing of anode and cathode is possible. With these lead-silver anodes an additional agent of colloidal silica and gum arabic is used in preference to glue, 2 lb. of each per ton of zinc.

### Electrolytic Zinc Refining

During the days of the great spread between the prices of brass special and prime Western spelter it was possible to make a profit by buying the latter and rolling anodes from it, which were then refined just as is electrolytic copper. However, as the zinc bubble subsided, it is understood that the profits of these companies did likewise, until they were forced to quit business.

**Loss of Zinc in Brass Melting.**—In some experiments carried on by H. M. THORNTON and HAROLD HARTLEY (Amer. Inst. of Metals, September, 1916) it was found that in melting an 87.5:10:2.5 red brass twice, that the loss was 3.56 per cent. of the zinc contents. Pouring temperature was about 1090°C.

### Treatment of Platinum Ores<sup>1</sup>

A scheme of separation suitable for an average platinum ore, like those produced in Russia or Colombia, will be found adaptable, with appropriate modifications, to almost any type of concentrated platiniferous material.

In the usual practice, the ore is first digested with aqua regia, fresh acid being added from time to time as long as any appreciable amount of metal dissolves. A mixture of four volumes of hydrochloric acid (sp. gr. 1.18), one volume of nitric acid (sp. gr. 1.42), and one volume of water is satisfactory for the purpose. The resulting solution contains the bulk of the platinum and palladium as well as the gold and most of the base metals present in the material. It will also contain iridium, rhodium, and small amounts of ruthenium which were present as minor constituents of the soluble alloys, but any osmium which dissolves escapes as the volatile tetroxide. Some or all of the silver will be in the solution because of the solubility of silver chloride in such a strongly acid medium. Osmiridium and other alloys containing iridium as a major constituent remain in the insoluble residue, together with most of the ruthenium, much of the rhodium and much of the non-precious mineral content of the sample. Some platinum and presumably palladium are likely to be present in the insoluble portion.

**General Separations.** *Treatment of the Aqua Regia Solution.* The first operation is to precipitate the bulk of the platinum with ammonium chloride. To prepare the solution for this precipitation the nitric acid and most of the excess of hydro-

<sup>1</sup> Excerpts from a paper by EDWARD WICHERS, RALEIGH GILCHRIST, and WM. H. SWANGER, presented at the February, 1928, meeting of the A. I. M. E.

chloric acid are removed by evaporation. A small amount of water is added to the hot sirupy residue to cause the decomposition of nitrous compounds of platinum, after which hydrochloric acid is added and the evaporation repeated. It is well to continue the evaporation each time until the temperature of the solution reaches  $140^{\circ}$  to  $150^{\circ}\text{C.}$ , unless the residue becomes pasty, in which case local overheating is likely to occur. The evaporation at high temperature probably causes the reduction of part of the iridium to the trivalent state, in which form less of this element will be precipitated with the platinum salt.

After the solution has been evaporated twice it is diluted so as to contain 50 to 100 grams of platinum per liter and set aside to permit silver chloride and other insoluble matter to settle. The solution is decanted or filtered from the insoluble residue, heated nearly to boiling and treated with ammonium chloride. Ammonium chloroplatinate separates at once. A small excess of ammonium chloride is desirable to reduce the solubility of the ammonium chloroplatinate, but a large excess should be avoided because it increases the contamination of the salt. The solution is cooled quickly and filtered at once to avoid contaminating the precipitate with the very impure salt which separates on standing. The precipitate is well drained and washed once or twice with a 20 per cent. solution of ammonium chloride, after which it is dried and ignited to sponge. The filtrate contains varying amounts of platinum but usually less than 5 per cent. of the platinum in the sample.

The next step depends on the nature and proportion of the other metals present. If there is a large amount of gold, it may be desirable to separate that metal by the addition of ferrous sulphate solution. The separation is rapid and complete, and the gold thus obtained is fairly pure. If much palladium is present, it may be desirable to add more ammonium chloride and a volume of nitric acid amounting to 20 or 30 per cent. of the solution. Digestion on the steam bath causes the precipitation of ammonium chloropalladate, accompanied by much of the iridium and platinum in the solution. However, the presence of nitric acid interferes greatly with the removal of the remaining precious metals. Usually the most convenient procedure is to precipitate all of the metals remaining in the solution, after the first precipitation of platinum, by means of zinc or iron. As it is very difficult to precipitate iridium completely in this way, the process must be continued for a long time, possibly for some days. Even then it is quite likely that some of the iridium will escape precipitation.

The precipitated metals are washed by decantation and after a sufficiently large amount of such material is accumulated it is attacked with aqua regia diluted with four volumes of water. Gold and palladium are very rapidly dissolved and platinum reasonably so. Comparatively little iridium, rhodium, and ruthenium will dissolve. If platinum predominates in the solution, it is best precipitated first, by means of ammonium chloride, as described. If not already separated, gold is then

removed by precipitation with ferrous sulphate, after which palladium is precipitated as described. The various precipitates, platinum, gold, and palladium, will contain more or less iridium, rhodium and ruthenium. The remainder of these metals together with unprecipitated platinum and palladium are recovered by precipitation with zinc as before, after evaporating the solution to eliminate most of the nitric acid.

*Residue after Treatment of Aqua Regia Solution.*—The residue of rhodium, iridium, and ruthenium may be worked up with the osmium-iridium material which remained undissolved in the original aqua regia treatment. However, if sufficient material is at hand to work the two lots separately it will be better to do so, because the former contains little or no osmium and a very minor amount of ruthenium and may therefore be handled somewhat more simply. If rhodium is predominant, the dried residue is intimately mixed with about two and one-half times its weight of sodium chloride and brought to dull red heat in a current of chlorine. This treatment converts a large part of the rhodium to the soluble rhodium chloride. Some of the iridium will also be converted to a double chloride, but this metal is less readily attacked than rhodium.

If iridium is predominant the residue is better attacked by fusion, at 600° to 700°C., with three parts of sodium hydroxide and one part of sodium peroxide in a silver, nickel or iron dish. A portion of the iridium is dissolved, probably in the form of a basic iridate. By far the greater part of the iridium from such a fusion remains insoluble in water but does dissolve in hot concentrated hydrochloric acid to form iridium chloride. The ruthenium present will be found largely in the aqueous solution obtained by leaching the fused alkaline mass. If only small amounts of ruthenium are involved it will be less tedious not to attempt to separate it at this point, but merely to concentrate it by precipitation together with iridium and any osmium by exactly neutralizing the alkaline solution with hydrochloric acid or sulphuric acid, adding a little alcohol and boiling. The small amount of metals remaining in the solution after this treatment may be recovered by reduction with zinc and hydrochloric acid. The treatment of this mixture of iridium, ruthenium, and osmium is discussed in the section dealing with the osmiridium fraction. Rhodium is not rapidly attacked by alkaline fusions. For this reason it is often found advantageous to alternate the treatments, sodium chloride + chlorine and sodium hydroxide + sodium peroxide, until all the material has been rendered soluble.

When the material that consists largely of rhodium and iridium has been brought into solution as chlorides, the two metals may be separated by either of two procedures, depending on the relative proportion of the two. Unless there is much more rhodium than iridium, a convenient way of effecting the first separation is to precipitate iridium as ammonium chloriridate. Before adding ammonium chloride the solution should be treated with a current of chlorine to oxidize any trivalent

iridium to the quadrivalent state. The solution should be concentrated so as to contain not less than 50 grams of the two metals in 1 liter. Enough ammonium chloride is added to react with the iridium present. A large excess should be avoided because of its interference with the subsequent concentration of rhodium. The ammonium chloriridate is separated by filtration, drained, and washed moderately well with a solution of ammonium chloride. It is likely to contain considerable rhodium as impurity. Most of the iridium remaining in the solution with the rhodium is recovered by evaporating the solution to dryness. This serves also to eliminate any excess of acid, which would be troublesome in the subsequent concentration of rhodium: The residue is taken up in sufficient water to dissolve any readily soluble salts, such as ammonium chloride, sodium chloride, or the double chlorides of rhodium, and filtered from the small precipitate of impure ammonium chloriridate. The filtrate is diluted so as to contain not more than 40 to 50 grams of rhodium in 1 liter, heated nearly to boiling and treated with sodium nitrite. This reagent first neutralizes the acid present and reacts with ammonium chloride to form ammonium nitrite, which decomposes in the hot solution. Rhodium and the other platinum metals, as well as certain base metals, are converted to soluble double nitrites, while other base metals, notably iron and tin, are precipitated as hydroxides. Heating is continued and more sodium nitrite added until the color of the solution becomes yellow or light brown. The precipitate is filtered off and treated for the recovery of the small amounts of platinum metals which it may contain. Ammonium chloride is added to the well cooled filtrate to precipitate ammonium rhodium nitrite. The ammonium chloride is added as a saturated solution in quantity sufficient to furnish the ammonium radical for  $(\text{NH}_4)_2\text{Rh}(\text{NO}_2)_6$ . The granular, white or yellowish salt is separated by filtration, washed with water and dried, or dissolved in hydrochloric acid for further purification. It is not suitable for direct ignition to sponge. Residual metals are recovered from the filtrate by means of hydrogen sulphide.

*Treatment of the Fraction Insoluble in Aqua Regia.*—The residue which remained undissolved in the original aqua regia treatment of the ore is converted into soluble form by fusion with sodium hydroxide and peroxide. As the grains of osmiridium are rather slowly attacked by the alkaline fusion, they are sometimes converted to a finely divided zinc alloy by melting with 5 to 10 parts of zinc at 600° to 800°C. for 2 to 3 hr. The molten mass is covered with fused zinc chloride to prevent rapid oxidation of the zinc and is occasionally stirred with a graphite rod. Treatment of the cooled melt with hydrochloric acid dissolves the excess of zinc and leaves a finely divided residue of osmium, iridium, etc., in the form of zinc alloys. The powder is washed and dried, but not ignited, and is then ready for the alkaline fusion. The aqueous extract from the fusion with sodium hydroxide and peroxide contains practically

all of the osmium and a large part of the ruthenium as well as minor amounts of iridium. The water-insoluble residue is digested for several hours on the steam bath with hydrochloric acid and the resulting iridium precipitated as ammonium chloriridate. The alkaline solution of osmium and ruthenium is transferred to a suitable distilling flask, described in the section on ruthenium. It is strongly acidified with nitric acid, then gradually heated to boiling, a current of air being used to carry the vapors of osmium tetroxide into the chain of receiving flasks. These flasks contain a 10 to 12 per cent. solution of sodium hyroxide. A little alcohol is added to all but the first one.

When no more osmium tetroxide distils, as may be observed by putting a fresh solution in the first receiving flask, the contents of the several flasks are combined and digested to insure the reduction of all osmium tetroxide to sodium osmate. More alcohol is added if needed. Practically all of the osmium may be separated from the ruthenium in this distillation. It has been observed, however, that it is not possible in this way to effect a complete separation of osmium from solutions to which alcohol has been added.

After cooling the solution in the distilling flask, it is made strongly alkaline with sodium hydroxide. The solution is then saturated with chlorine, thereby converting ruthenium to the tetroxide, which distils readily when the temperature is raised to 80° or 90°C. The current of chlorine is continued during the distillation but is greatly diluted with air. The receiving flasks in this case contain hydrochloric acid diluted with four volumes of water. A little alcohol is added to all of the receivers except the first one. When the quantity of ruthenium distilling over decreases, the solution is boiled gently and the distillation continued as long as oily drops of ruthenium tetroxide appear in the delivery tube. Without cooling the solution, more sodium hydroxide is added and saturated with chlorine, whereupon more ruthenium is distilled. When very little ruthenium tetroxide is obtained on repeated distillation, the remaining iridium, ruthenium, etc., are precipitated by adding a little alcohol to the neutralized solution from the distilling flask and boiling. The contents of the receiving flasks are combined and digested to complete the reduction of ruthenium tetroxide, more alcohol being added if needed. The resulting solution is evaporated and set aside for further purification, or ruthenium may be precipitated with ammonium chloride.

**Electrolytic Calcium Arsenate<sup>1</sup>.**—White arsenic is dissolved in 10 per cent. caustic soda in the proportion 198  $\text{As}_2\text{O}_3$ :25  $\text{NaOH}$ . This solution is electrolyzed between iron electrodes. About 1 per cent. of the arsenic present is deposited at the cathode. Most of the oxygen evolved at the anode goes to oxidizing the arsenic. The solution is then filtered and a

suspension of calcium hydroxide added, enough lime being used to form a basic compound that does not burn the cotton plants, thus:



The calcium arsenate is then filtered off and the sodium hydroxide used to dissolve more arsenic. The tanks are "series", 30 amp. per sq. ft., the tanks are never completely emptied, as the residual arsenate prevents the precipitation of metallic arsenic on the cathode. NOTE.—The Dept. of Agriculture provides that commercial calcium arsenate must contain at least 40 per cent.  $\text{As}_2\text{O}_5$  of which less than 0.7 per cent. must be water soluble, and must bulk from 80 to 100 cu. in. per lb.

### Iron Refining—Cowper Cowles Process

The electrolyte consists of ferrous chloride, cresol-sulphonic acid being used as an addition agent. Scrap iron is kept in the bath to insure its reduction and iron-oxide is suspended in it both to keep the bath neutralized and to polish the cathode deposit by friction. The unannealed deposit contains 394 volumes of hydrogen per volume of iron, while if the cathode is heated to a dull glow this is reduced to  $1\frac{3}{4}$ :1. The voltage is about 1.5 per cell, and the current density high, about 7 am. per sq. decimeter. (See also pp. 366 and 767.)

### Carnotite Ore Treatment

Colorado treatment of carnotite ores was thus described by H. D. d'AGUIAR (*Chem. Met. Eng.*, Nov. 2, 1921). The ore is ground to 60 mesh and placed in a tank built of acid-proof brick, where it is treated with enough hydrochloric acid to dissolve the V, U, Fe, Ca, etc. The ore is stirred vigorously during solution. After solution is complete sulphuric acid is added in sufficient quantity to precipitate the barium and calcium. Uranium and vanadium are now in solution; radium in suspension. The solution is decanted and the insoluble residues washed with stirring several times. The first washes are added to the first decantate; the last washes are used as first washes on succeeding lots of ore.

The strong solution and washes are filter pressed and brought to slight acidity with sodium carbonate, after which sodium nitrate is added and the tank heated by steam to boiling. Vanadium oxide with some iron and uranium is precipitated. After filtering off the vanadium precipitate the solution is made alkaline with sodium hydroxide, throwing down sodium uranate together with the rest of the vanadium and some iron.

The filter press cake of sulphates is digested under pressure with sodium carbonate until the barium and radium sulphates are converted to carbonates and these carbonates are filter pressed, then dissolved in hydrochloric acid and filter-pressed to free from silica and again precipitated as sulphates and again



converted to carbonates and then to chlorides. These chlorides are then ready for crystallization. For extended description of this process see LIDDELL's "Handbook of Chemical Engineering," or "Handbook of Non-Ferrous Metallurgy."

### Recovery of Radium from the Olary Ores

Because of the general interest in the extraction of radium the following excerpts are given from S. RADCLIFF's description of the recovery of radium from the Olary (Australia) ores at the Radium Hill Co.'s plant at Syndey, N. S. W. (*Min. and Eng. Review*, Oct. 5, 1914).

The ore is dry crushed at the mine to pass a sieve of 20 holes to the linear inch, and is then concentrated magnetically; the concentrates, amounting to about 30 per cent. of the ore crushed, being forwarded to Sydney for treatment.

The concentrates have the composition: CaO, 0.55 per cent.; PbO, 0.16; Fe<sub>2</sub>O<sub>3</sub>, 17.4; FeO, 16.9; MnO, tr.; thorium, cerium, lanthanum and didymium oxides, 3.27; Cr<sub>2</sub>O<sub>3</sub>, 0.85, U<sub>3</sub>O<sub>8</sub>, 1.6; V<sub>2</sub>O<sub>5</sub>, 0.86; TiO<sub>2</sub>, 45.85 per cent.; SiO<sub>2</sub>, 12.70.

As the concentrates are insoluble in acids, a fusion process is necessary to effect the initial decomposition. The concentrates are mixed with three times their weight of salt cake (acid sulphate of soda) and fused in a reverberatory furnace of sufficient capacity to take 500 kilos of concentrates and 1500 of salt cake in a single charge. Three charges can be put through in 24 hours. The fused product, crushed to 8 mesh, is fed, in small amounts at a time, into wooden vats filled with agitators. Cold water is fed continuously into the vats at the bottom and an overflow is provided near the top. By suitably adjusting the conditions, it is possible to separate out on the bottoms of the vats a considerable amount of comparatively coarse material which is almost free from radium and uranium. The turbid liquid overflowing carries in suspension the radium, lead and barium as sulphates, together with a considerable amount of finely divided silica; while in solution we have the uranium rare earths, and part of the iron and acid earths contained in the ore.

The coarse residues are removed from the vats daily, rewashed to free them from any undissolved fused product and sent to the dump.

The overflow from the dissolving vats is pumped to large lead-lined settling tanks and allowed to stand all night. The "slimes" settle completely in 12 hours, and the clear liquid is drawn off daily and treated for the recovery of the uranium. The slimes which amount, when dried, to approximately 10 per cent. of the weight of the concentrates, are collected weekly and treated for the recovery of the radium as described below.

The further steps in the treatment process may conveniently be described under two heads:

- (a) The recovery of the uranium.
- (b) The recovery of the radium.

### Recovery of the Uranium

The clear solution containing the uranium and much of the iron and other bases in the concentrates, together with a large amount of sodium salts, is fed into series of vats containing a measured excess of a mixture of carbonate and bicarbonate of soda; and heated and agitated by means of steam jets. The iron, with most of the other bases present, is precipitated, while the uranium goes into solution together with some of the rare earths. The bulky iron precipitate is separated partly by settlement and partly by means of vacuum filters. It is difficult to handle and cannot be washed effectually; a portion of the uranium is therefore unavoidably discarded along with this precipitate. The uranium solution is made just acid with sulphuric acid, heated and the carbon dioxide expelled by a brisk current of air. The uranium is then precipitated by the addition of ammonia. The ammonium uranate is thickened somewhat in conical settling tanks and then further thickened to a pulp in a hydro-extractor. This pulp is dried and dehydrated in large muffles. The dehydrated product is broken up and washed repeatedly with hot water. This treatment removes the bulk of the sodium salts, and a product is obtained which on drying contains about 75 per cent. of  $U_3O_8$ . An analysis of this, together with that of the iron precipitate, is given below. Prior to analysis the iron hydroxide was twice dissolved and reprecipitated with ammonia to free it from the large amount of sodium salts present. The washed precipitate was dried, ignited and analyzed.

	Uranium product	Iron precipitate
Insoluble matter.....	3 0	.....
Titanium dioxide.....	.....	8.11
Ferric oxide.....	9 41	74.65
Uranoso-uramic oxide.....	16 6	2.7
Rare earths.....	1 57	7.36
Lead oxide.....	0.51	.....
Vanadic oxide.....	.....	1 2
Chromium oxide.....	.....	5 81
Sodium salts.....	8.21	.....

### Recovery of the Radium

The thickened insoluble residue or slime from the settling tank is mixed with half its dry weight of strong sulphuric acid and allowed to stand for several days. It is then washed, first by decantation and then on a vacuum filter, till the washings give only a very slight precipitate with barium chloride. The acid treatment and washing reduces the bulk of the slime considerably, removing large amounts of acid earths and iron salts.

The washed slime in quantities of about 200 kilos, dry weight, is then boiled in a large steel boiler under pressure with an excess of a 20 per cent. solution of sodium carbonate for two days, the solution being replaced once during the boiling. This treatment dissolves a large amount of silica, and converts much of the lead, radium, and barium sulphates to carbonates. The slime is then washed till the wash water gives no reaction for sulphates; this takes 2 days for each lot of 200 kilos. The washed slime is then fed into a warm dilute solution of hydrochloric acid, agitated for a couple of hours, and allowed to settle all night. The clear solution is siphoned off and the lead, barium, and radium precipitated as sulphates. After washing once by decantation, the slime is again treated as above described. Two treatments suffice to extract most of the radium, but the slime is reserved for a further treatment, if necessary. The plant as at present arranged can treat the slime from 10 tons of concentrates per week. The weekly yield of crude sulphate is about 12 kilos.

A number of experiments, both in the laboratory and on the working scale were made to see if the sulphates in the slime could be reduced by heating the material with carbonaceous substances, or else in a current of some reducing gas, but the results so far have not been encouraging.

The treatment of the crude sulphate is now carried out as follows, not as in the paper read by the author before the Royal Society of New South Wales in 1913: The crude sulphate is dried and fused with three times its weight of caustic soda in an iron pot. The melt is poured, cooled, and digested with hot water. Most of the lead goes into solution. The insoluble residue is washed till free from soluble sulphates, and then digested in a rotating boiler under a steam pressure of about 60 lb. This converts the bulk of the sulphates of barium, radium and lead to carbonates. The carbonates are well washed on a filter and dissolved in hydrochloric acid. The solution is taken to dryness to remove any colloidal silica, and the residue is taken up with water and a little HCl. In addition to barium and radium chlorides, small amounts of iron and lead chlorides, together with considerable quantities of barium, lanthanum, didymium, and thorium chlorides are present. This solution is now saturated with hydrogen chloride gas; the barium and radium are precipitated quantitatively as chlorides, almost free from the other substances present. The chlorides are filtered off, dried, dissolved in water, and purified from the small amounts of second and third group elements in the ordinary way. They are finally precipitated as carbonates by means of pure  $\text{Na}_2\text{CO}_3$ , and the carbonates dissolved in HCl. The solution is now ready for fractional crystallization for the recovery of the radium.

The economic success of the process depends on the fact that it is possible to decompose the uranium minerals without bringing the whole ore complex into solution, and that comparatively small amounts of reagents are required to effect this. The tail-

ings sent to the dump, amounting to about 50 per cent. of the material smelted, are almost free from radium and uranium, and appear to consist mainly of unaltered rutile. The radioactive slimes amount to about 1 ton from every 10 tons of concentrates, and are one-fifth of the weight of the tailings. As the alpha ray activity of the slimes is thirty times that of the tailings, it appears that the slimes carry over 80 per cent. of the radium originally present in the concentrates. That is, the initial fusion of the concentrates enables a great concentration of the radium to be made by mechanical means before continuing the chemical treatment.

The rare earths in the concentrates distribute themselves in the course of the iron hydroxides carrying 7.36 per cent. rare earths, the uranium product containing 1.57 per cent. and the crude sulphates. The rare earths extracted from the iron hydroxide precipitate are only very feebly radioactive. The activity does not increase with time, and is due to the presence of 0.06 per cent. of thorium oxide, with its attendant ionium. The earths extracted from the uranium product are also only very feebly active. The rare earths carried down with the crude sulphate contain a considerable proportion of the thorium in the ore, and appear also to carry most of the actinium. This is to be expected, as it is well known that actinium can be extracted from a solution by precipitating barium sulphate in it. A thorium-ionium preparation worked up from the earths in the crude sulphate has an activity several hundred times as great as that of  $U_3O_8$ .

The rare-earth mixture, containing about 3 per cent. of rare earths in addition to the constituents enumerated, is fused in an iron crucible with excess of sodium hydroxide containing some sodium carbonate, the melt extracted repeatedly with hot water, the insoluble residue digested with excess of sodium carbonate under a steam pressure of 90 lb., the carbonate residue washed, treated with dilute hydrochloric acid, the solution evaporated to dryness, the residue treated with water, the silica filtered off, and the solution saturated with hydrochloric acid gas (to precipitate the radium and barium) and filtered. The filtrate, containing the actiniferous rare earths, is evaporated to dryness and the residue further treated to separate actinium. *Ionium* appears to be chemically inseparable from thorium, so that by extracting and purifying the latter by any of the well-known methods an active ionium product is obtained.

## DUST AND FUME CONDENSATION

The problem of dust catching is one of reducing the speed of the gas sufficiently. JAMES DOUGLAS, in writing of the Copper Queen, says that all true dust would settle from a velocity of  $2\frac{1}{2}$  ft. per second in a chamber 125 ft. long, which rate of settlement can be materially increased by wire screens placed across the direction of flow. Later it was understood that the rate adopted

was 5 ft. per second. Hence dust settlement reduces itself to a question of large chambers and of temperature reduction, which reduces volume and hence speed. The reduction of temperature can best be achieved by thin-walled steel flues—often, as at Mammoth, by passing the gas through a great number of parallel steel pipes. These pipes may or may not be cooled by a water spray. Another method is to make the top of a brick flue out of a series of cast-iron pans which are set step-fashion, so that each overflows into the next, the feed being just sufficient to equal the combined evaporation from all the pans.

The use of baffles and tortuous windings in the flues has largely been given up, as it is usually conceded that these act more as stirrers than settlers. However, settlement is helped by plates hung so that they are parallel to the travel of the gas (FREUDENBERG plates), or by wires across the travel (ROESING'S wires).

A stack is of practically no value as a dust settler. It may be needed to give the necessary draft through the flues, or to discharge the gas so high that it will be diluted enough not to be unendurable by the time it reaches the ground, but that is about all. When a dust particle starts up a stack it usually emerges on top. The WISLICIENUS stack consists of a large number of radial openings near the top of the stack. The wind enters through these and quickly dilutes the effluent.

The ferrous metallurgist uses the centrifugal gas washer (a test of a THIESSEN washer is given in the succeeding pages) and at the Ducktown Sulphur Copper & Iron Co.'s works a Feld scrubber took out 95 per cent. of the fume in the smelter gas. This was preparatory to running the gas through a coke bed heated to 1100 to 1300°C. by an electric current, which reduces the  $\text{SO}_2$  to S. (W. F. LAMOREAUX, *Eng. and Min. Jour.*, Feb. 4, 1922.)

For fume condensation the most successful treatment seems to be the COTTRELL system of electrostatic discharge, described at more length below, filtration through bags, or precipitation by thoroughly atomized water (SCHÜTTE-KOERTING system). Scrubbers in which the gas is allowed to bubble through water amount to very little, although their efficiency can be raised, usually, by oils or acids in the water. Figures on baghouse work are given on p. 784. While a baghouse should pay in lead smelting or on silver furnaces, it probably does it only indirectly in copper work—by keeping the smoke farmers quiet.

Gas control must be by chemical means, except that  $\text{SO}_2$  is very easily condensed by the COTTRELL system. Sulphur dioxide and trioxide are controlled completely at the Ashio mines, Japan, by passing all the effluent gases through lime water. The SPRAGUE system adds zinc oxide to the flue gases and filters out the zinc salts in the baghouse. The HALL process aims to reduce the sulphur oxides to sulphur as formed in the furnaces using hydrocarbon vapors as the reducing agent. YOUNG'S thiofen process aims at the reduction of the sulphur vapors in the flues by hydrocarbon gases.

### Electrostatic Precipitation (Cottrell Process)

This is best performed in tubes in which the tube forms one electrode and a wire placed concentrically with it forms the other. The discharge should not be one produced by an alternating current, but should be a silent discharge with the wire preferably the negative anode. The breakdown voltage with most smoke is about 32,000. The presence of fine points due to hardened deposits, kinks in the wire, rough spots, etc., tends to localize the discharges from the wire, and even though there be many such points, the cleaning action of such discharges is much below that of a uniform field around a straight wire (A. F. NESBIT, "*Trans. A.I.M.E.*," Third Midwinter Convention, Feb. 17 to 19, 1915).

At the Hooker Electrochemical Co.'s Plant 30,000 cu. ft. of gas per minute is treated with a power consumption of 3 to 5 kw. At the Garfield, Utah, smelter 200,000 cu. ft. of gas per minute is treated with an expenditure of 50 kw. The electrode spacing is  $2\frac{1}{2}$  in. and the potential is 50,000 volts. At Tooele, Utah, 20,000 cu. ft. of gas per minute requires less than 5 kw. Each of the two units contains 48 pipes 12 in. in diameter by 15 ft. long.

The chief developments from 1916 to 1927 have been:

In 1916-1917 Schmidt and Bradley demonstrated the value of gas conditioning or humidification, particularly in the precipitation of non-conductive materials, such as zinc oxide, etc.

In 1918 Wolcott<sup>1</sup> showed conclusively that with non-conductive deposits on the collecting electrodes a disturbance was set up, resulting in a corona being formed on the particles making up the deposit, causing a lowering of the arcing voltage, thus necessitating reduction of the operating voltage and a consequent diminution or a complete elimination, frequently, of a corona discharge from the discharge electrodes. The elimination of such corona discharge prevented further precipitation taking place. Conditioning of the deposit with conductive material or of the gases, by the addition of conducting materials or by temperature reduction, or both, overcame this difficulty.

In 1923-1924, SCHMIDT and ANDERSON demonstrated an improved form of collecting electrode, known as the "graded resistance" electrode, by the use of a special cement mixture applied in the form of a plate, with embedded conductors, placed in such relation to the discharge electrode, that a poorly conducting medium was placed in series with the spark gap between the discharge electrode and the embedded grounded conductor. This resulted in a greatly reduced size of precipitator, operating without serious arcing and uniformly precipitating the dust contained in the gases.

ARTHUR J. BOYNTON recommends cooling all gas to be cleaned below the dew point, usually below 90°F. (*Proc. A.I.M.E.*, February, 1928, New York meeting). Although this involves the loss of the sensible heat of the gas, he insists that the presence of the water vapor involves a loss greater than any possible gain through high temperature of the gas as used. He also advocates a separation of the coarser particles of dust by dry separation, as the coarse particles have a high metallurgical value, while much of the fine dust, recovered as sludge, should be thrown away. More thorough cleaning for gas to be used in gas engines is indicated than when the gas is to be used under boilers or in underfiring coke ovens. In German practice, a dry dust catcher for each furnace is common, with a central washing plant. This plant will cost, exclusive of dust-catchers and collecting and distributing mains, at least \$12,500 per 100 tons of pig iron per day. Operating costs will run from \$0.00177 to \$0.00283 per 1,000 cu. ft. of gas, corresponding approximately to \$0.225 to \$0.40 per ton of pig iron.

The standard of cleanness in German practice permits a maximum content of dust of 0.04 grains per cu. ft. of gas. With a disintegrator the content usually runs from 0.002 to 0.009 gram per cu. ft. With the Halberger-Beth bag filters the dust may be brought down to 0.02 gram per cu. ft.

The disintegrator is a type of apparatus originally applied to the fine crushing of coal. It consists of a shell similar to a fan casing and provided with a rotating shaft on which is mounted a disk. The disk carries successive rows of bars which rotate rapidly between corresponding circular rows of bars fixed to the casing. The system is sprayed with water from points near the rotating shaft and the spray is thrown uniformly into the space occupied by the rotating and stationary bars through which the gas passes.

The disintegrator should be preceded by a cooling tower, which will use 20 to 24 gal. of water per 1,000 ft. of gas. The disintegrator itself will use 4 to 7½ gal. of water additional per 1,000 ft. of gas and from 6 to 12 kw., depending on how lightly the disintegrator is loaded, both water and power consumption going up as the load goes down. The dust content of the cleaned gas of course increases with the load, the low figures given above in the consumption being reached at the upper permissible limit of 0.004 gram of dust per cu. ft. of gas.

Bag cleaning is also practiced in Germany, with automatic methods of bag cleaning. The system requires close control, as the limits of operation lie between 50 and 100°C. There is a drop in the ordinary bag system equal to about 4 in. of water, which means this much pressure must be carried at the furnace top, or else the system worked under a vacuum, with grave risk of air leakage and consequent explosion.

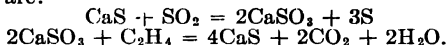
COTTRELL treatment is also practiced, the largest present plant (1928) being at Witkowitz in Czechoslovakia, treating 35,000 M per minute, but the high humidification necessary gives considerable trouble.

With bag cleaning the cost appears to be about \$0.00283 per M; one figure as low as \$0.00169 is given. The cost at Witkowitz is about \$0.00146 per M. These figures would probably be increased by about 30 per cent. in the United States.

A full review and complete bibliography of this process is given in the *Eng. and Min. Journ.* of Feb. 26, 1916.

### Thiogen Process

The thiogen process was devised by S. W. YOUNG of Stanford University, in an attempt to eliminate sulphur gases from smeltery smoke. The process contemplates passing a mixture of the sulphur-bearing gases and a hydrocarbon reducing agent of the ethylene series over a catalyst of calcium sulphide. The reactions are:



In practice, when a mixture of sulphur dioxide and hydrocarbon vapor pass together over a mixture of calcium sulphide and calcium sulphite, the reactions proceed simultaneously. The hydrocarbon gas is generated from fuel oil. The process has been tried at the Penn Smelting Works, Campo Seco, Cal., but the catalyst poisons easily and it does not appear that it is yet a commercial process. (See *Eng. and Min. Journ.*, Feb. 15, 1913.)

### Hall Process

An invention of E. J. HALL, by which sulphur-bearing gases were to be treated immediately after their formation with a reducing gas containing some hydrocarbons. Elemental sulphur was to be set free, which was to be recovered in a centrifugal scrubber. The process was tried at the Balaklala smeltery in California, but is understood to have given trouble through the formation of allyl compounds that rendered the neighborhood extremely offensive, and through the fact that the washers did not do what was expected of them. (See *Eng. and Min. Journ.*, July 5, 1913, for a fuller account of the theory of the process.)

### Bag-house Data

Some data were given by ANTON EILERS, before the International Congress of Applied Chemistry in 1912, concerning bag houses of the American Smelting & Refining Co. The Murray, Utah, plant treats furnace charges low in lead (10–12 per cent.) and the precious metals. They are wet and carry up to 4 per cent. of sulphur. Its total cost was \$127,195 including the cost of 4,032 cotton bags and the distributing flue, etc. The building was  $216\frac{1}{2} \times 90\frac{1}{2}$  ft., and was  $51\frac{1}{2}$  ft. to the roof trusses. Stacks carried the fumes out of the building and it was necessary to place a lead-lined pan at a sufficient distance under the stack not to interfere with the draft, to catch the con-



densed moisture dripping from the stack sides, which otherwise drops on and eats away the bags. The bags are 18 in. in diameter and 30 ft. long, shaken from outside. The average life of cotton bags costing \$2.136 a piece, was 17 months, 11 days. They were replaced by woolen bags from the Buell Mfg. Co., St. Joseph, Mo., costing \$4.7185 apiece, which it is estimated last 4 years. Other bags were bought from the Laporte Woolen Mills, Laporte, Ind., at a cost of \$4.784. There are 570,012 sq. ft. of filtering surface for filtering 165,000 cu. ft. of gas per minute, but if one compartment was down, there were  $2\frac{1}{2}$  sq. ft. of filtering surface per cubic foot per minute. If over 24 in. of fume is allowed to accumulate in the cellars under the bags, spontaneous combustion begins. Therefore, when the cellar of any compartment contains 24 in. of dust, it is damped off from the bags, hot coals thrown in on the dust, and the dust sintered by its own combustion. In this Murray bag house the following percentages of the metals charged in the furnaces were recovered: Lead, 1.269 per cent.; silver, 0.063 per cent.; gold, 0.049 per cent.; and copper, 0.0118 per cent. The operating cost in  $4\frac{2}{3}$  years was \$76,853; treatment charge on the material recovered was \$69,290, while the value of the metals recovered was \$152,691, showing an apparent gain of \$6,547, but if proper interest and amortization charges be placed against it, there is a net loss of \$58,746. These figures show that, taking the immediate financial outcome only, bag houses are not profitable in lead-smelting works, except where it is an object to stop smoke-suits.

### Omaha Plant

This plant treats gases from converters treating leady copper mattes; from blast furnaces treating rich charges; and from zinc-oxide furnaces. The following facts are given for the converter bag house. The secret of long life for the bags is said to be thorough cooling of the gases before admission, and a good vacuum over the bags, drawing off the exhaust gases rapidly. The converter bag house has 68,000 cu. ft. in the flue; 67,000 cu. ft. in the cellar; 174,000 cu. ft. in the bag chamber; has 940 bags, 18 in.  $\times$  28 ft. long, having 124,000 sq. ft. of filtering area; treats the gases from converting about 45 tons of blister, or about 5,200,000 cu. ft. of gas which usually passes in 15 hr. out of the 24. The gas temperature at the bag house is 152°F. This bag house showed a profit of \$98,712 per year on a \$42,000 cost.

Some other miscellaneous bag-house data have been collected as follows:

Unwashed-wool bags have been found to be the best for filtering purposes because they last much longer than any other kind. Unwashed wool is wool which has not had the animal grease scoured out.

The method of neutralizing sulphurous gases at the United States lead smeltery at Bingham Junction is to pass the gases

through steel flues exposed to the atmosphere in order to get cooling effect; then to add powdered lime to combine to form calcium sulphate. Zinc oxide is also very valuable for neutralizing these gases, but it is expensive. However, since the works have zinc concentrates to treat, these will be mixed with crushed coal or coke, and roasted in furnaces near the flues. The zinc-oxide fumes resulting will be conducted into the main flues after the lime has been added, about 100 ft. further on, so that the lime shall have had time to act. A considerable velocity of gases is required in order to keep the lime in suspension, 2200 ft. per minute, which was the velocity of the copper blast-furnace gases in the flues.

The gases should travel at least 100 ft. after the neutralizing agents have been put in, in order to give them time to act.

Apart from their greater resistance to sulphuric acid, sulphuric anhydride, and selenium dioxide, wool bags are superior to cotton for filtering purposes because of the fine hairs lying on the surface, which arrest all the finest possible particles of the fume before they reach the actual pores of the filtering medium.

The bags at the United States lead plant are 34 ft. 6 in. long  $\times$  18 in. in diameter. When tied in place they give a net filtering area 31 ft.  $\times$  18 in. diameter, equal to 141 sq. ft. of filtering surface per bag. One sq. ft. of bag filter cloth is allowed for 0.7 cu. ft. of gas at 0°C. These bags weigh 7 to 8 lb. each and cost 45 cts. per linear yard. The freight on bags per pound is  $2\frac{1}{2}$  cts. and the hanging cost is estimated at 15 cts. per bag. This makes the total cost per bag in place \$5.50. The mechanical shaking device installed in this bag house costs at the rate of \$2 per bag.

In the Mammoth bag-house experiments, 1 sq. ft. of filter cloth filtered 0.75 cu. ft. of gas at 0°C. under  $\frac{1}{16}$ - to  $\frac{1}{8}$ -in. water pressure. There was no apparent deterioration of bags at 50° to 100°C. When temperature falls below 45° the bags become damp and permit the fume to escape. In dry weather, the temperature can be as low as 25°C. and the bags filter all right. The cotton bags used were of 50 mesh and the wool bags of 20 mesh.

At the United States lead bag house the ideal temperature for lead blast-furnace gases is considered 70°F., and must not exceed 90°. The ideal temperature for roaster gases is 100° and must not exceed 120°F.

At the United States lead bag house the blast-furnace bag dust is high in arsenic. This dust ignites of its own accord in the dust chamber basement and sinters to a sort of clinker which is treated in the arsenic plant. This clinker contains on an average 22 per cent. arsenic and 32 per cent. lead. This product goes to the Brunton furnace, 20 ft. diameter  $\times$  4 ft. high, encased in brick, fired with coke, and with the hearth revolving once in about 9 min. The arsenic volatilizes and passes off as  $As_2O_3$ . The lead sinters and is worked off the hearth into hoppers by rabbles. This averages 40 per cent. lead

and 9 per cent. arsenic. The  $\text{As}_2\text{O}_3$  fume discharges into brick settling chambers  $200 \times 20 \times 10$  ft. high for the first 50 ft., and 8 ft. high the rest of the length. At intervals of 8 ft. in this chamber are baffle walls to make the gases zigzag and deposit acid on the walls. The product from this chamber averages 97 to 99 per cent. arsenic and is further refined in a reverberatory furnace 25 ft.  $\times$  15 ft.  $\times$  6 ft., coke fired. This chamber is kept at  $500^\circ$  at 30 ft.,  $200^\circ$  at 100 ft., and  $120^\circ$  at 175 ft. from the furnace. If the end chamber gets too hot the acid goes off and is lost. This produce is crystalline and has to be ground for the market. It assays 99.87 per cent. pure and is much better than the foreign article.

In installing any bag house the quantity of gases and the temperatures will be known. It is required to determine the amount of cooling surface necessary to reduce this temperature to one which would not injure the bags, and then to determine the number of bags required to filter this amount of gas. The length of the cooling pipes is more or less fixed by the contour of the ground, and the available sites for the bag house. The sizes of the pipes are determined by the quantity of the gas flowing.

Experiments in radiation and conduction through No. 8 steel plate show that the rate of heat transmission is equal to 0.042 B.t.u. per minute per square foot of cooling surface per degree difference between temperature of gas and external air. The weight of this gas may be taken at 0.08 lb. per cubic feet at  $0^\circ\text{C}.$ , and its specific heat at 0.2375.

A typical bag-house fume is Pb, 52.5 per cent.; Zn, 3; S, 5.4; As, 14.2; Sb, 1.6.

### Chimneys<sup>1</sup>

The velocity of discharge of a gas from a chimney is as follows:

$$V = \sqrt{2gh \left( \frac{t''}{t'} - 1 \right)}$$

where  $V$  = Velocity in feet per second.

$g$  = Acceleration due to gravity.

$h$  = Height of chimney in feet.

$t'$  = Absolute temperature of external air.

$t''$  = Absolute temperature of the hot gas.

Since the velocity varies as the square root of the height, high chimneys do not pay. Indefinite increase in temperature of the exhaust gas is not an advantage, either, for although the velocity increases with increased temperature, the increase in volume offsets this. The maximum results are obtained at  $273^\circ\text{C}.$  over outside air.

Draught power of a chimney in inches of water is: \*

$$d = h \left( \frac{7.64}{t'} - \frac{7.95}{t''} \right)$$

<sup>1</sup> W. R. INGALLS, "Metallurgy of Zinc and Cadmium."

**EMERGENCY REPAIR KINKS**

By A. W. BULL

In the operation of chemical plants where emergency repairs must be made with the least possible loss of time, work is frequently considered impossible until hot solutions have been removed from the tank, floor or sump where the repair is to be made. If the breakdown is due to a pump failure or a pipe line stoppage the removal of hot solutions may be difficult. Emergency work under such circumstances can be done, however, without complete draining, by men wearing rubber boots filled with cold water. A pair of hip boots filled with cold water will enable the wearer to walk through or stand in nearly boiling water for at least ten minutes particularly if the toes are frequently wiggled to circulate the water inside the boot.

It is sometimes necessary to do work inside hot tanks that have just recently been drained. In some cases the tanks cannot be cooled with water alone because of the excessive volume required. A method which will frequently suffice is to use a large atomizer made by bringing a water and air hose to the same  $\frac{3}{4}$ -in. tee and having a 6-in. piece of pipe as nozzle in the third tee opening. In this way a small amount of cold water combined with the air blast gives a remarkable cooling effect on the air in a steaming hot tank and permits emergency repair work without waiting for the tank itself to cool.

**Precipitation of Silver from Cyanide Solution<sup>1</sup>**

Precipitation from cyanide solution is by deposition of the dissolved metal upon zinc, either in the form of shavings or dust, or upon aluminum in the form of dust, or by electrolysis. Zinc dust is at present the most usual precipitant, although aluminum has some advantages, in that it does not form any cyanogen compound. Electrolysis has been a popular process, but at the present time is considered too expensive for general use. One ounce of silver requires about one ounce of zinc or one-third of an ounce of aluminum for its precipitation.

**SULPHUR-SAND CEMENT<sup>2</sup>**

Sulphur-sand cement is composed of 1 part sulphur and 1.4 parts quartz sand ground to pass at least a 60-mesh screen. The mixture is heated to about 150°C. when it flows nicely and is sufficiently above the melting point of sulphur, 114°C., to prevent sudden chilling. The fact that sulphur begins to thicken above 156°C. and becomes so viscid that it will not flow at 180°C. must be borne in mind or there will be difficulty in working the cement. This is possibly the most satisfactory general cement available for low temperature work. It is readily handled and remarkably strong, has a tenacious bond is free from cracking and inert to most solutions. It will be

<sup>1</sup> *Eng. and Min. Journ.*, Jan. 9, 1915.

<sup>2</sup> E. J. HALL, *Eng. and Min. Journ.*, July 17, 1915.

found valuable for large-scale work, as well as in the laboratory. It was developed by CHARLES S. BRADLEY for use in his copper-leaching process.

SIZES AND CAPACITIES OF BULLION MOULDS<sup>1</sup>

Inside measure			Capacity, gold, Troy oz.	Silver, Troy oz.	Weight of mould, lb.
Length, inches	Width, inches	Depth, inches			
1	$\frac{5}{8}$	$\frac{1}{2}$	4	2	1
$1\frac{1}{2}$	1	$\frac{3}{4}$	10	5	1
$2\frac{1}{4}$	$1\frac{1}{16}$	1	25	12	1
$3\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{8}$	50	25	3
$3\frac{1}{2}$	2	2	95	50	6
4	2	$1\frac{3}{4}$	100	56	7
$4\frac{1}{4}$	$2\frac{1}{4}$	2	136	76	9
$4\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{4}$	180	100	10
5	$2\frac{1}{2}$	$2\frac{1}{4}$	244	134	10
$5\frac{1}{8}$	$2\frac{3}{4}$	$2\frac{1}{4}$	250	140	10
$5\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$	295	166	11
$5\frac{1}{2}$	3	$2\frac{3}{4}$	365	200	12
$5\frac{3}{4}$	3	$2\frac{3}{4}$	375	208	13
$6\frac{1}{2}$	$3\frac{1}{4}$	$3\frac{1}{4}$	550	300	15
$6\frac{3}{4}$	$3\frac{1}{2}$	$3\frac{1}{4}$	620	340	19
$7\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{4}$	730	400	28
8	$3\frac{3}{4}$	$3\frac{1}{2}$	910	500	35
9	$3\frac{3}{4}$	$3\frac{1}{2}$	1015	600	38
$9\frac{1}{2}$	4	$3\frac{1}{2}$	1285	700	40
$9\frac{1}{2}$	$4\frac{1}{2}$	$3\frac{1}{2}$	1448	800	41
10	4	4	1470	810	42
$10\frac{1}{2}$	4	4	1650	900	55
11	$4\frac{1}{2}$	4	1830	1000	65
11	$4\frac{1}{2}$	$4\frac{1}{2}$	2200	1200	72
$11\frac{1}{2}$	5	5	2750	1500	76

<sup>1</sup> As made by FRASER & CHALMERS.

### Briquetting

For the purpose of agglomerating flue dusts and fine ores there are a number of binders and methods. Among the binders may be mentioned cement, concentrator sludge, milk of lime, molasses refuse (which usually leads to a convention of flies assembling from all the neighboring states), ferric- or ferrous-sulphate solutions, magnesium- or calcium-chloride solution (the use of 5 to 10 per cent. of magnesium- or calcium-chloride solution, equivalent to 0.25 to 2 per cent. of  $MgCl_2$  or  $CaCl_2$ , followed by compression, constitutes the patented SCHUMACHER process), and various asphaltic and tarry residues.

Of the various methods used with these binders may be mentioned hand-moulding, brick-press moulding (square form), round briquettes (CHISHOLM-BOYD-WHITE machine), briquettes cut from continuous stream (CHAMBER's brick machine), the use of bags, and agglomeration in HUNTINGTON-HEBERLEIN pots or DWIGHT-LLOYD roasters for lead ores, and on DWIGHT-LLOYD machines or in cement kilns for flotation concentrates.

For metallic chips the RONAY process is probably best.

This method is one for briquetting metallic chips without a binder. The divided metal particles are subjected in a mould to pressures of about 30,000 lb. per square inch. The briquette is allowed to remain under pressure a sufficient time to expel all the air and moisture, having been previously freed from dust and dirt.

A general résumé of the subject of briquetting for iron-blast furnace work is abstracted by the *Journal of the Society of Chemical Industry*, Oct. 30, 1915, from *Le Génie Civil*, 1913, p. 306, and *Revue de Metallurgie*, 1915, p. 138. To be serviceable in a blast furnace, briquettes should satisfy the following tests: (1) fall from a height of 3 to 4 m. on to a metal plate without being reduced to powder, and withstand a pressure of about 140 kg. per square centimeter; (2) withstand a temperature of 900°C. without being reduced to powder; (3) stand in water for some time without softening; (4) withstand steam at 150°C. without being reduced to powder; (5) be sufficiently porous to absorb 12.5 to 16 per cent. by volume of water on being immersed for 25 minutes. The briquettes should be free from sulphur, arsenic, and other objectionable materials, and the cost of briquetting must not be greater than the difference in value of the ore in lump and as smalls.

**Methods of Briquetting.**—(1) (YEADON). 5 to 10 per cent. of slaked lime is added and the mixture made into a paste with water. Briquettes are formed under a pressure of 400 kilos per square centimeter and are placed in the open air to dry and harden. This requires at least 2 months. To avoid this delay steam under pressure is sometimes used, or about 10 per cent. of sawdust is added to the mixture and the briquettes are heated to 1200°–1400°C., when the wood carbonizes and the particles of ore frit together. (2) A mixture of equal parts of lime and sand is used as the agglomerant. (3) (SCHUMACHER). Fresh blast-furnace dust is briquetted with magnesium chloride as binder. (4) Basic blast-furnace slag is used as the agglomerant for dust, hardening being effected by high-pressure steam. If the dust is deficient in lime, 4–4.5 per cent. of this material is added. (5) An intimate mixture of ore, limestone, and moistened cement is briquetted under a pressure of 400 kilos per square centimeter. The briquettes are serviceable after standing in the open air for 3 or 4 days. (6) (WEISS). Briquettes containing 5–6 per cent. of slaked lime are compressed at 300 kilos per square centimeter and subjected to the action of carbon dioxide under a pressure of 20 kilos per square centimeter, first in the cold and then hot. The treatment requires

about 5 hours, after which the briquettes are serviceable. (7) (RONAY). Blast-furnace dust or roasted pyrites is compressed hydraulically into briquettes, without the addition of binders, under a pressure of about 1000 kilos per square centimeter. (8) (GRÖNDAL). Impure ores are ground and concentrated in magnetic separators. The ore-mud is formed under small compression into briquettes, which are then passed on wagons of special construction through gas-fired tunnel furnaces. The highest temperature reached is 1300°–1400°C., which causes the particles to frit together and drives off sulphur. The briquettes are of high quality. (9) DURYEA process of briquetting metal chips. The chips are dried at a high enough temperature to expel moisture and burn off oil; free iron is removed magnetically; the material is briquetted at pressures up to 14,000 lb. per sq. in., air being exhausted before the final pressure is applied.

### Blast-furnace Practice<sup>1</sup> (1928)

The tendency in Europe, as with us, is to use turbines for new construction or replacement of old steam or even gas engines. The lower construction cost and the lower operating cost, when they can have high steam temperatures and pressures, together with their efficiency, is the cause of this change to turbines, in both high and low pressure.

The present trend is to equip plants with modern, efficient steam boilers, turbines, etc., and gradually work into high-pressure superheated steam equipment to accomplish a saving. One company has just completed a 375 to 400 lb., 700° superheated steam installation and turboblowers with this end in view. Some of our new steam plants are using 350 lb. working pressure.

But little scrap is charged in German furnaces, because of difficulties with the bucket tops generally used. Besides it is needed for open-hearth furnaces.

So far as could be learned, no plants in Germany are screening their ore and sintering the fines. They are, however, using a great deal of sinter.

Flue dust and Swedish concentrates are mixed and sintered at many plants, giving a good product containing about 66 per cent. iron. Some plants also add coke breeze; 6½ per cent. carbon is about the lowest that will give good sinter.

Flue dust and bluebilly, or purple ore, are mixed extensively, as the latter is cheap and runs from 40 to 55 per cent. Fe. Meiderich works has a 2-strand, 39¾-in. by 82-ft. Dwight-Lloyd machine using this mixture. The charge contains 45 per cent. Fe, 6½ per cent. C, 13 per cent. moisture and is laid on a ¾-in. crushed limestone bed to protect the pans. Blast-furnace gas is used for ignition. The furnaces at this plant have used up to 50 per cent. sinter with good results. The Volklingen plant at Saarbrücken, France, working on minette ores with 32 to 35 per cent. iron content, has been

<sup>1</sup> Excerpts from a paper read before the American Iron and Steel Institute, at New York, Oct. 26, 1928, by C. A. MEISSNER.

screening for  $1\frac{1}{2}$  years, sintering the fines with flue dust, coke dust and mill scale. Other plants in the Luxemburg region are contemplating doing this soon.

Belt transmission of ores is nowhere in use. They see no objection to it, however. Transmission of all sorts of materials with cable buckets is very generally used all over Europe.

Crushing of coke is not generally practiced in Germany. The Vulkan plant is crushing to  $1\frac{1}{2}$  to  $2\frac{3}{8}$  in., screening out the walnut size for domestic and the breeze for sinter. They are obtaining good results and other plants are now starting to do this.

At the Hamborn furnaces in Germany daily average production through a year on 16-ft., 5-in. hearth furnaces, in good condition and with good ore mixture, has been as high as 835 tons. This they attribute largely to the open nature of the burden. Daily averages for a month are sometimes as high as 850 tons and they had made as high as 920 tons daily for a month's run. Productions of 950 to 1,000 tons are occasionally made for a day or two, but not over any period of time. The present daily average production, because of poor ore mixture resulting from the Swedish mine strike, is 700 tons per furnace. Average production for a campaign is about 1,200,000 tons. Varying amounts of sinter are used.

On good ore mixture slag volume is about 1,100 lb. per ton of iron. On present poor ore mixture about 1,760 lb. per ton of iron. On good ore mixture the coke rate is from 1,716 to 1,870 lb. per ton on larger furnaces, depending of course on age of furnace.

Blast temperature is generally 950 to 1100°F. throughout Germany; higher heats slow the furnaces down too much. Hamborn is using 1200°F. However, one plant at Saarbrücken, France, expects to go to 1550°F. on minette ores and sinter. The general feeling is that there is no limit to stove heat, except what the furnace will take without slowing down.

Heating surface per stove on the new Hamborn furnace is 102,000 sq. ft. Four two-pass side-combustion chamber stoves, with square checkers having  $2\frac{3}{8}$ -in. brick and  $3\frac{1}{2}$ -in. holes, are being constructed.

Top temperatures run from 300 to 480°F.

Average wind on 16-ft., 5-in. furnaces is 49,600 to 59,000 cu. ft. per minute. New furnace will blow 71,000 to 75,000 cu. ft. per minute. Gas engines are used exclusively at this plant for blowing, and electric generators. The high first cost of gas engines is weakening their position in Germany. New blast furnaces at Essen are installing 90,000 cu. ft. per minute turboblowers.

Blast pressure at the Hamborn plant is about  $14\frac{1}{2}$  lb. per square inch. Ordinary tuyères are used, but patented Venturi type tuyères will be tried.

The cleaning of blast-furnace gas by electrical precipitation is arousing a great deal of interest throughout Central Europe. Among the reasons given for this interest are the following:



1. Power consumption of electric cleaning is about one-tenth that of wet washing.

2. Cost of sludge disposal from wet washers is high.

3. Difficulty of waste water disposition is serious in some sections.

4. Shortage of water at some plants makes wet washing objectionable.

5. Several plants are putting in turboblowers and so do not need such clean gas as would be required for gas engines.

6. The saving of sensible heat, even after gas is partially cooled in primary coolers, is considered to more than offset the extra moisture carried by the gas.

Efforts to clean hot gas electrically have met with little success abroad. The feeling is general that the economical unit is one which has a thermostatically controlled spray tower preceding it, so that the gas to be cleaned will have a uniform temperature, ranging from 140 to 210°F. in different installations. The reduced volume of the cooled gas makes possible a smaller unit, and the uniform temperature permits much cheaper construction than would be possible if the high temperatures during slips had to be guarded against. It has also been established that, for a given cleanliness of gas, higher gas temperature necessitates lower velocity through the cleaner. This condition would therefore call for a considerably larger cleaner for gas at, say, 400°F. than is needed for gas under 200°F.

The feeling exists generally that the advantages of high sensible heat and low moisture content of hot gas are more than offset by the money saved in building the smaller, more efficient and more cheaply constructed unit using cooled gas.

Where gas is to be used for gas engines as well as stoves and boilers, normal practice is to install a primary cleaner for the latter, and a secondary cleaner followed by hurdle cooling towers for the engine gas.

It may be of interest to note that the injection of water into a blast furnace at or near the tuyères, which has been tried in Germany, is not generally received with favor. Neither is the proposition of withdrawing gases from the upper part of the furnaces.

It may be interesting to make a few notations of American blast-furnace practice compared to the European practice.

In large American blast-furnace plants, the aim today is that each individual blast-furnace stack should produce 700 tons or more of iron per day, unless there are local conditions which make this commercially uneconomical. A great many furnaces have passed this mark, while there are several stacks which produce 850 to 950 and occasionally over 1,000 tons of iron per day. At one plant with eight furnaces operating during the month of July, 1928, not one stack produced less than 700 tons iron per day, while one of these stacks averaged 979 tons per day for the month, with a coke consumption of 1,838 lb. per ton of iron. Average coke consumption for the whole

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plant for this month was 1,862 lb.; average iron production was 782 tons.

From this it may be noted that while several furnaces in Germany are doing excellent work, their best furnaces are not producing any greater tonnages than our large modern furnaces. What we have to learn, however, is the larger use of sinter, especially as applied to fine dust and possibly as applied to fine ores.

COMPARATIVE BLAST-FURNACE PRACTICE<sup>1</sup>  
(Period Ending Apr. 1, 1919)

	Mark Mfg. Co. No. 1, 3 months	Inland Steel Co. No. 3, 12 months
Total pig iron produced, tons . . .	52,101	205,353
Average daily production of pig iron, tons . . .	578.9	569.6
Average daily production of pig iron per 100 cu. ft. essential furnace volume . . .	2.59	2.86
Pounds coke consumed per ton iron produced . . .	1,976	1,926
Pounds stone consumed per ton iron produced . . .	901	918
Pounds Bessemer slag consumed per ton iron produced . . .	85	22
Pounds ore consumed per ton iron produced . . .	4,323	4,656
Pounds scale consumed per ton iron produced . . .	95	125
Pounds scrap consumed per ton iron produced . . .	42	8
Pounds scrap produced per ton iron	41	134
Pounds fine dust produced per ton iron	73	290
Pounds sintered dust consumed per ton iron . . .	none	72
Average cubic feet air blown per minute at 60°F . . .	40,688	44,190
Average cubic feet air blown per pound coke at 60°F . . .	49.9	56.0
Air blown per minute adjusted to 56 cu. ft. per lb. coke . . .	45,660	44,190
Average blast temperature, deg. F . . .	954	1,002
Average blast pressure, pounds per square inch . . .	16.4	19.7
Number of tuyères actually blown through . . .	9	12
Size of tuyères actually blown through . . .	5 in. and 6 in. × 12 in.	5½ in. × 12 in.
Average gas temperature, deg. F . . .	334	297
Average gas pressure in inches of water . . .	42	35
Average per cent. of water added to ore charged . . .	none	0.9
Average composition of iron produced:		
Silicon, per cent. . . . .	1.04	1.04
Sulphur, per cent. . . . .	0.03	0.035
Phosphorus, per cent. . . . .	0.19	0.297
Manganese, per cent. . . . .	1.09	2.03

COMPARATIVE BLAST-FURNACE PRACTICE. *Continued*

	Mark Mfg Co. No. 1. 3 months	Inland Steel Co. No. 3. 12 months
Average composition of slag produced:		
Silica, per cent.....	34 55	33 23
Alumina, per cent.....	14.75	15 92
CaO, per cent.....	46.16	44 80
MgO, per cent.....	1 98	1 95
Sulphur, per cent.....	1 54	1 42
FeO, per cent.....	0 46	0 71
MnO, per cent.....	0.91	1 97
Per cent. of pig iron over 0.050 per cent. sulphur .....	2 34	Not recorded
Per cent. of pig iron over 1.25 per cent. silicon .....	12.39	Not recorded
Per cent. iron between 0.75 and 1.25 silicon and not over 0.04 sulphur		
Method of charging:	Not recorded	73.39
Dump large bell .....	{ Coke..... 9,200 Ore .. 22,500 Stone 4,500	{ Ore .. 14,000 Coke .. 3,700 Stone .. 5,000 Ore .. 14,000 Coke... 7,400
Dump large bell. . .		
Height from tuyères to 6 ft. below bell .....	71 ft. 2 in.	69 ft. 0 in.
Height from tuyères to top bosh plates.....	13 ft. 4 in.	12 ft. 8 in.
Height from top bosh plates to stack batter .....	5 ft 9 in.	9 ft. 5 in.
Height of stack batter .....	44 ft. 0 in.	38 ft. 7 in.
Height from stack batter to 6 ft. below bell .....	8 ft. 1 in.	8 ft. 4 in.
Diameter nose to nose of tuyère coolers .....	18 ft. 6 in.	17 ft 3 in.
Diameter nose to nose of top bosh plates .....	23 ft. 3 in.	21 ft. 9 in.
Diameter of lining at bottom of stack batter.....	22 ft. 6 in.	21 ft. 4 in.
Diameter of lining at top of stack batter .....	17 ft. 0 in.	16 ft. 6 in.
Diameter of lining 6 ft. below closed bell .....	17 ft. 0 in.	16 ft 6 in.
Volume calculated from above dimensions .....	22,371	19,891

From *Min. and Met.*, February, 1920.

**Oxygen in Cast Iron.**—According to J. E. JOHNSON, JR., oxygen in cast iron is desirable. It increases the strength, gives it a higher solidifying temperature and gives a white chill with higher silicon than an iron not containing it. The oxygen content can be controlled by the addition of manganese. But oxygen introduced by high bed, heavy charges, low coke ratio, excessive melting rate, and high blast results in burnt iron, which is entirely different from iron containing oxygen which has been correctly melted. Controlling the oxygen is a much easier way of controlling the chill than by attempting to do it through varying the silicon. (JOHNSON, *Trans.*

*A.I.M.E.*, 1914, vol. 50 p. 344; STORK, *Bull. A.I.M.E.*, June, 1919, p. 951.)

### Iron and Steel

**Cast Iron.**—Cast iron is defined as any alloy of iron and carbon with over 2.2 per cent. C.

**White Cast Iron.**—Cast iron chilled so quickly from the molten state that all of the carbon remains combined as  $\text{Fe}_3\text{C}$ . It is brittle and hard.

**Gray Cast Iron.**—This is cooled so slowly that some of the cementite has split into iron and carbon, the latter being deposited as graphite.

**Malleable Cast Iron.**—On reheating white cast iron and holding for some time at 800 to 1100° the cementite slowly decomposes and liberates carbon. This carbon is much more finely disseminated than the graphite in gray iron, consequently, the structure is not weakened in the same way.

**Wrought iron** is malleable iron aggregated from pasty particles without fusion, and containing so little carbon that it does not harden usefully when rapidly cooled.

**Steel** is iron usefully malleable in some one range of temperature and cast from the molten state into a mass initially malleable or aggregated from pasty particles without subsequent fusion, but differing from wrought iron in containing sufficient carbon to harden usefully when quickly cooled from above its critical range.

### Transformation Points of Iron

**$A_0$ —210°C.**—This is found in all iron-carbon alloys and is the temperature above which the compound  $\text{Fe}_3\text{C}$  is nonmagnetic. Such a point is found in all ferromagnetic substances and is called the Curie point.

**$A_1$ —725°C. (and up).**—Temperature of the iron-carbon eutectoid (maximum solubility of carbon in iron).

**$A_2$ —768°C. +.**—A point found in pure iron and its alloys, being the Curie point of iron. Formerly called the transformation from  $\alpha$  to  $\beta$  iron, although  $\beta$  iron is now called nonmagnetic or paramagnetic  $\alpha$  iron.

**$A_3$ —906°C.**—A true polymorphic transition point. It is displaced both up and down by various alloying elements.  $\alpha$  iron to  $\gamma$  iron.

Nearly all of the important physical properties of iron change at the  $A_3$  point, and there is a large heat change.

**$A_4$ —1400°C.**—A true polymorphic transition point,  $\gamma$  iron to  $\delta$  iron. It is displaced up and down by various alloying elements.  $\delta$  iron has the same space lattice as  $\alpha$  iron.

The transformation point  $A_3$  varies for the same iron according to the conditions under which they are observed. When observed during heating they have the letter *C* inserted (for the French "chauffage"). The letter *r* signifies "recalescence" on the cooling curve. The  $A_3$  point is the mean between the observed  $A_{c3}$  and the observed  $A_{r3}$  temperatures.

## Heat Treatment Definitions

The following proposed definitions have been formulated by a joint committee\* of the American Society for Testing Materials, Society of Automotive Engineers, and American Society for Steel Treating.

By "critical temperature range," as used in the definitions, is meant that temperature range in the diagram given by Howe:

**1. Heat Treatment.**—An operation, or combination of operations involving the heating and cooling of a metal or an alloy in the solid state.

**NOTE.**—This is for the purpose of obtaining certain desirable conditions or properties. Heating and cooling for the sole purpose of mechanical working are excluded from the meaning of this definition.

**2. Quenching.**—Immersing to cool.

**NOTE.**—Immersion may be in liquids, gases, or solids.

**3. Hardening.**—Heating and quenching certain iron base alloys from a temperature either within or above the critical temperature range.

**4. Annealing.**—Annealing is a heating and cooling operation of a material in the solid state.

**NOTE (A).**—Annealing usually implies a relatively slow cooling.

**NOTE (B).**—Annealing is a comprehensive term. The purpose of such a heat treatment may be:

**NOTE (E).**—To remove gases.

(a) To remove stresses.

(b) To induce softness.

(c) To alter ductility, toughness, electrical, magnetic or other physical properties.

(d) To refine the crystalline structure.

In annealing, the temperature of the operation and the rate of cooling depend on the material being heat-treated and the purpose of the treatment.

Certain specific heat treatments coming under the comprehensive term "annealing" are:

**A. Normalizing.**—Heating iron base alloys above the critical temperature range followed by cooling to below that range in still air at ordinary temperature.

**NOTE.**—In the case of hypereutectoid steel, it is often desirable to heat above the  $A_{cm}$  line.

**B. Spheroidizing.**—Prolonged heating of iron base alloys at a temperature in the neighborhood of, but generally slightly below, the critical temperature range, usually followed by relatively slow cooling.

**NOTE.**—(a) In the case of small objects of high carbon steels, the spheroidizing result is achieved more rapidly by prolonged heating to temperatures alternately within and slightly below the critical temperature range.

(b) The object of this heat treatment is to produce a globular condition of the carbide.

**C. Tempering** (also termed **Drawing**).—Reheating, after hardening, to some temperature below the critical temperature range followed by any rate of cooling. .

**NOTE.**—(a) Although the terms “tempering” and “drawing” are practically synonymous as used in commercial practice, the term “tempering” is preferred.

(b) Tempering, meaning the operation of hardening followed by reheating, is a usage which is illogical and confusing in the present state of the art of heat treating and should be discouraged.

**D. Malleabilizing.**—Malleabilizing is a type of annealing operation with slow cooling whereby combined carbon in white cast iron is transformed to temper carbon and in some cases the carbon is entirely removed from the iron.

**NOTE.**—Temper carbon is free carbon in the form of rounded nodules made up of an aggregate of minute crystals.

**E. Graphitizing.**—Graphitizing is a type of annealing of cast iron whereby some or all of the combined carbon is transformed to free or uncombined carbon.

**5. Carburizing** (Cementation).—Adding carbon to iron base alloys by heating the metal below its melting point in contact with carbonaceous material.

TOTAL HEAT AND HEAT CAPACITY OF PURE IRON

Temp. deg. C.	Total heat, mean, per gram	True specific heat, per gram
0	0	0.104
100	11.17	0.120
200	23.25	0.124
300	36.04	0.132
400	50.28	0.147
500	65.80	0.1635
600	82.6	0.178
700	100.77	0.228
790	125.3	0.211
800	125.2	0.212
900	149.6	0.220
1000	168.0	0.146
1100	183.0	0.154
1200	198.4	0.154
1300	213.8	0.154
1400	229.6	0.154
1500	250.2	0.143
1535 (solid)	252.3	0.143
1535 (liquid)	317.2	0.176
1600	319.8	0.176
A <sub>1</sub> - 906°	4.9 cal. per gram	
A <sub>4</sub> - 1400°	1.7 cal. per gram	
m.p. - 1535°	64.9 cal. per gram	

NOTE.—The term “carbonizing” used in this sense is undesirable and its use should be discouraged.

**6. Case Hardening.**—Carburizing and subsequent hardening by suitable heat treatment, all or part of the surface portions of a piece of iron base alloy.

*Case.*—That portion of a carburized iron base alloy article in which the carbon content has been substantially increased.

*Core.*—That portion of a carburized iron base alloy article in which the carbon content has not been substantially increased. The terms “case” and “core” refer to both case hardening and carburizing.

**7. Cyaniding.**—Surface hardening of an iron base alloy article or portion of it by heating at a suitable temperature in contact with a cyanide salt, followed by quenching.

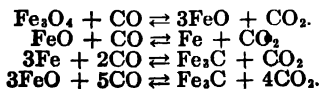
#### REDUCTION OF IRON ORES BY CARBON MONOXIDE<sup>1</sup>

Temp. deg. C.	Fe <sub>3</sub> O <sub>4</sub> -FeO per cent. CO <sub>2</sub>	Equilibrium, per cent CO	FeO-Fe, per cent. CO	Equilibrium, per cent. CO <sub>2</sub>
561	...	...	53.6	46.4
627	43.5	56.5	57.0	43.0
662	39.7	60.3	58.4	41.6
720	35.2	64.8	60.7	39.3
863	25.5	74.5	65.9	34.1
963	20.4	79.6	69.2	30.8
1070	16.4	83.6	72.4	27.6
1175	15.2	84.8	75.5	24.5

<sup>1</sup> HEIHACHI KAMURA, *Trans. A.I.M.E.*, February, 1925, meeting; also A. MATSUBARA, *Trans. A.I.M.E.*, 1922, Vol. 67, p. 3-35.

Temp. deg. C.	FeO-Fe <sub>3</sub> C equilibrium, per cent. CO	Fe-Fe <sub>3</sub> C equilibrium, per cent. CO
800	86.0	92.3
850	88.6	94.5
900	90.3	95.4
1000	92.9	97.0
1100	95.6	98.9

The equations governing the above data are:



## THERMOCHEMISTRY OF THE IRON BLAST FURNACE

Reaction	Calories
$3\text{FeO} + \text{Si} = \text{FeSiO}_3 + 2\text{Fe}$	= + 100,040
$\text{FeO} + \text{Mn} = \text{MnO} + \text{Fe}$	= + 26,200
$8\text{FeO} + 2\text{P} = \text{Fe}_3\text{P}_2\text{O}_8 + 5\text{Fe}$	= + 168,700
$\text{FeO} + \text{C} = \text{CO} + \text{Fe}$	35,600
$\text{SiO}_2 + \text{CaO} = \text{CaSiO}_3$	+ 15,200
$\text{P}_2\text{O}_5 + 3\text{CaO} = \text{Ca}_3\text{P}_2\text{O}_8$	+ 78,700
$\text{FeSiO}_3 + \text{CaO} = \text{CaSiO}_3 + \text{FeO}$	+ 5,600
$\text{Fe}_3\text{P}_2\text{O}_8 + 3\text{CaO} = \text{Ca}_3\text{P}_2\text{O}_8 + 3\text{FeO}$	+ 26,340
$\text{MnSiO}_3 + \text{CaO} = \text{CaSiO}_3 + \text{MnO}$	+ 10,200
$\text{Mn}_3\text{P}_2\text{O}_8 + 3\text{CaO} = \text{Ca}_3\text{P}_2\text{O}_8 + 3\text{MnO}$	+ 19,100
$\text{FeSiO}_3 + \text{C} = \text{SiO}_2 + \text{Fe} + \text{CO}$	45,600
$\text{MnSiO}_3 + \text{C} = \text{SiO}_2 + \text{Mn} + \text{CO}$	- 67,200
$\text{Fe}_3\text{P}_2\text{O}_8 + 3\text{C} = \text{P}_2\text{O}_5 + 3\text{Fe} + 3\text{CO}$	- 159,160
$\text{FeO} + \text{C} = \text{Fe} + \text{CO}$	- 35,600
$\text{MnO} + \text{C} = \text{Mn} + \text{CO}$	- 61,800
$\text{Fe}_3\text{P}_2\text{O}_8 + 3\text{SiO}_2 = 3\text{FeSiO}_3 + \text{P}_2\text{O}_5$	- 22,360
$\text{Ca}_3\text{P}_2\text{O}_8 + 3\text{SiO}_2 = 3\text{CaSiO}_3 + \text{P}_2\text{O}_5$	- 31,900
$\text{P}_2\text{O}_5 + 5\text{C} = 2\text{P} + 5\text{CO}$	- 260,500

**Loss of Heat in Subterranean Gas Conduits.**—The following table is given by M. QUASEBART in *Stahl und Eisen*, 1913, p. 492.

Gas temperature, °C.	Loss in deg per meter of length, °C.
700-600	3.5
600-500	3.0
500-400	2.5
400-300	2.0
300-200	1.0

## STEEL CONVERTING—HEAT EFFECT OF OXIDIZING 1 KG. OF MATERIAL

	Heat of oxidation	Formation of slag	Total heat developed	Chilling effect of blast, radiation, etc.	Net heat available for raising temperature	Theoretical rise in temperature
						Deg C.
Silicon...	7,000	.....	7,000	1,688	5,312	188
Manganese	1,653	98	1,751	430	1,321	51
Iron (to FeO) . . .	1,173	159	1,332	422	910	33
Iron (to Fe <sub>2</sub> O <sub>3</sub> )	1,746	159	1,905	825	1,080	42
Titanium . . . . .	4,542	.....	4,542	1,022	3,520	133
Aluminum . . . . .	7,272	.....	7,272	1,305	5,967	224
Nickel . . . . .	1,051	159	1,210	378	832	33
Chromium . . . . .	2,344	.....	2,344	887	1,457	56
Carbon (to CO <sub>2</sub> ) . .	8,100	.....	8,100	3,936	4,164	143
Carbon (to CO) . . .	2,430	.....	2,430	2,572	- 142	- 5
Phosphorus . . . . .	5,897	2,572	8,469	{ 2,477 2,253 <sup>1</sup> }	3,739	133

<sup>1</sup> Chilling effect of lime added, preheated to 600°.



**Basic-lined Open Hearth (Monell Process)<sup>1</sup>**

Fifty tons pig iron at 1300°C. run in on 15 tons of ore (90 per cent.  $\text{Fe}_2\text{O}_3$ ; 10 per cent.  $\text{SiO}_2$ ) also heated to 1300°C. There is 2,000 lb.  $\text{CaO}$  on the ore. The reaction requires about 20 minutes.

## ANALYSIS OF METAL

	On running in	After reaction
Carbon.....	3 50	3 00
Silicon.....	2 00	0 00
Phosphorus.....	0 75	0 00
Manganese.....	0 50	0 00
Iron.....	93 25	97 00

	Heat evolved	Cal.
Si to $\text{SiO}_2$ ..	$2,000 \times 7,000 =$	14,000,000
P to $\text{P}_2\text{O}_5$ .....	$750 \times 5,892 =$	4,419,000
Mn to $\text{MnO}$ ..	$500 \times 1,653 =$	826,500
C to $\text{CO}$ ..	$471 \times 2,430 =$	1,144,500
$\text{SiO}_2$ to $\text{FeO} \cdot \text{SiO}_2$	$7,286 \times 144 =$	1,049,200
$\text{CaO}$ to $3\text{CaO} \cdot \text{P}_2\text{O}_5$ ..	$2,000 \times 949 =$	1,898,000
		23,337,200

## PIG-IRON CONVERTING DATA

	C, per cent	P, per cent	Si, per cent	Mn, per cent	S, per cent
Charge.....	2 98	0 10	0 94	0 43	0 06
After blowing 9 min. 10 sec.....	0 04	0 11	0 02	0 01	0 06

Slag formed:  $\text{SiO}_2$ , 63.56 per cent.;  $\text{Al}_2\text{O}_3$ , 3.01;  $\text{FeO}$ , 21.39;  $\text{Fe}_2\text{O}_3$ , 26.3;  $\text{MnO}$ , 8.88;  $\text{CaO}$ , 0.90;  $\text{MgO}$ , 0.36.

Gases produced:  $\text{CO}_2$ , 5.20 per cent.,  $\text{CO}$ , 19.91;  $\text{H}_2$ , 1.39;  $\text{N}_2$ , 73.50 per cent.

<sup>1</sup> J. W. RICHARDS, "Metallurgical Calculations," Vol. II

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### Heat Balance Sheet (Blowing 22,500 Lb. of Above Pig)

Heat in converter body at starting.....	8,034,970
Heat in melted pig iron.....	6,750,500
Heat in spiegeleisen.....	750,000
Heat in blast.....	86,580
Heat of oxidation.....	4,510,800 <sup>1</sup>
Heat of formation of slag.....	59,890
Total on hand and developed.....	<u>20,192,740</u>

Heat in converter body at finish.....	7,183,770
Heat in finished steel.....	8,632,750
Heat in slag.....	1,582,350
Heat in escaping gases.....	2,786,000
Heat absorbed in decomposing moisture..	182,130
Heat conducted to the air.....	34,630
Heat lost by radiation.....	25,240
Total accounted for.....	<u>20,426,870</u>

<sup>1</sup> Derived as follows:

C to CO <sub>2</sub> .....	1,139,670 cal.
C to CO.....	1,309,280 cal.
Si to SiO <sub>2</sub> .....	1,422,400 cal.
Mn to MnO.....	327,130 cal.
Fe to FeO.....	268,150 cal.
Fe to Fe <sub>2</sub> O <sub>3</sub> .....	44,170 cal.
	<u>4,510,870 cal.</u>

### Tempering Ordinary Steel

Deg.	Color
200.....	Yellow
250.....	Brown
300.....	Light blue
350.....	Dark blue

	Heat absorbed	Cal.
Fe <sub>2</sub> O <sub>3</sub> to FeO.....	18,900 × 573 =	10,829,700
FeO to Fe.....	4,681 × 1,173 =	5,490,800
Fe <sub>3</sub> C to Fe <sub>3</sub> +C.....	471 × 705 =	332,000 (?)
FeSi to Fe+Si.....	2,000 × 931 =	1,862,000 (?)
Fe <sub>3</sub> P to Fe <sub>3</sub> +P.....	750 × 1,400 =	1,050,000 (?)
		<u>19,564,500 (?)</u>

**BALANCE SHEET OF IRON BLAST FURNACE<sup>1</sup>**  
(Per 1000 Units of Pig Iron)

Charges		Pig iron		Slag		Gases	
Ore.....	1530.2						
Fe <sub>2</sub> O <sub>3</sub> ...	1314.9	Fe....	920.4	FeO.....		O.....	394.5
FeO.....	60.6	Fe....	46.2	FeO.....	1.2	O.....	13.2
SiO <sub>2</sub> ...	84.2	Si.....	6.0	SiO <sub>2</sub> ...	69.6	O.....	8.6
MnO.....	9.6	Mn.....	0.25	MnO.....	9.3	O.....	0.1
Al <sub>2</sub> O <sub>3</sub> ...	11.6			Al <sub>2</sub> O <sub>3</sub> ...	11.6		
CaO.....	34.1			CaO.....	34.1	O.....	0.03
MgO.....	14.8			MgO.....	14.8		
P <sub>2</sub> O <sub>5</sub> ...	0.092	P.....	0.04			O.....	0.05
S.....	0.153	S.....	0.07	CaS.....	0.19		
Cu.....	9.11	Cu.....	0.11			O.....	0.01
Limestone....	115.8						
Fe <sub>2</sub> O <sub>3</sub> ...	0.2			FeO.....	0.2	O.....	0.02
SiO <sub>2</sub> ...	3.6			SiO <sub>2</sub> ...	3.6		
Al <sub>2</sub> O <sub>3</sub> ...	0.4			Al <sub>2</sub> O <sub>3</sub> ...	0.4		
CaO.....	62.2			CaO.....	62.2		
MgO.....	0.2			MgO.....	0.2		
P <sub>2</sub> O <sub>5</sub> ...	0.007	P.....	0.003			O.....	0.004
S.....	0.001			CaS.....	0.0		
CO <sub>2</sub> .....	49.1					CO <sub>2</sub> ...	49.1
Charcoal.....	682.0						
C.....	547.7	C.....	27.0			C.....	520.7
N.....	0.5					N.....	0.5
O.....	24.1					O.....	24.1
Fe <sub>2</sub> O <sub>3</sub> ...	2.2			FeO.....	2.0	O.....	0.2
SiO <sub>2</sub> ...	1.3			SiO <sub>2</sub> ...	1.3		
CaO.....	6.1			CaO.....	5.9	O.....	0.06
MgO.....	0.7			MgO.....	0.7		
P <sub>2</sub> O <sub>5</sub> ...	0.046		0.02			O.....	0.03
S.....	0.116			CaS.....	0.25		
K <sub>2</sub> O.....	3.4			K <sub>2</sub> O.....	3.4		
H <sub>2</sub> O.....	95.8					H <sub>2</sub> O.....	95.8
Blast.....	2416.8						
O <sub>2</sub> .....	557.7					O.....	557.7
N <sub>2</sub> .....	1859.1					N.....	1859.1
Totals.....	4744.8		1000.0		220.8		3543.7

<sup>1</sup> J. W. RICHARDS, "Metallurgical Calculations," Vol. II.

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**HEAT BALANCE, IRON BLAST FURNACE<sup>1</sup>**  
(Per 100 Kg. of Iron)

Heat developed	' Dry blast	Wet blast
C to CO.....	92,950 Cal.	131,220
C to CO <sub>2</sub> .....	206,955 Cal.	213,030
Heat in blast.....	37,850 Cal.	39,385
Solution of carbon in iron.....	2,820 Cal.	2,820
Formation of slag.....	4,260 Cal.	4,425
	<b>344,835 Cal.</b>	<b>390,880</b>

<sup>1</sup> J. W. RICHARDS, "Metallurgical Calculations," Vol. II.

Heat accounted for	Dry blast	Wet blast
Reduction of iron.....	165,870	165,870
Reduction of silicon.....	7,000	7,000
Expulsion of CO <sub>2</sub> .....	18,666	18,666
Evaporation of moisture.....	11,342	11,342
Heat in waste gases.....	23,799	43,836
Decomp. of blast moisture.....	3,225	14,511
Heat in slag.....	29,280	30,450
Heat in pig iron.....	32,500	32,500
Heat in cooling water.....	14,922	15,525
Lost by radiation and conduction.....	37,791	51,180
	<b>344,835</b>	<b>390,880</b>
Carbon burnt at tuyères.....	58.05	75.3
Total fixed carbon charged.....	67.8	84.3
Proportion burnt of tuyères.....	85.6	89.3
Fixed carbon really available.....	62.9	79.4
Proportion burnt at tuyères.....	92.3	94.8

CUPOLA CHARGES IN STOVE FOUNDRIES<sup>1</sup>

	Foundry A	Foundry B	Foundry C	Foundry D <sup>2</sup>	Foundry E
Bed of coke.....	1500	1600	1600	1800	1900
First iron charge.....	5000	1800	4000	5600	5000
All other iron charges.....	1000	1000	2000	2900	2000
First charge of coke.....	200	150	200	200	200
Second charge of coke.....	200	130	200	200	175
Four next charges.....	150	130	150	200	175
Six next charges.....	120	100	150	200	175
All other charges.....	100	100	150	200	175

<sup>1</sup> KENT's, "Mechanical Engineers' Pocket Book."<sup>2</sup> A very high melting ratio for stove plate. About 8- to 14-oz. blast is necessary for good melting. The metal loss will probably run from 4 to 6 per cent.

## WASHING GASES WITH THIESSEN WASHER

	Hochdahl		Schalke	Hörde		Rom-bach
	Appa-ratus I, hot un-cleaned gas	Appa-ratus II		Appa-ratus I, cool cleaned gas	Appa-ratus II	
Dust, grains per 1000 cu ft:						
Before washing.....	2.6	2.6	1.3-1.7	1.1	1.0	0.87
After washing.....	0.017	0.008	0.008	.....	0.004	0.008
Water, grains per 1000 cu. ft.:						
Before washing.....	7.8	10.4	15.0	13.9	15.8	18.3
After washing.....	3.1	2.2	% vol. 12.20	1.5	1.3	13.9
Temperature of gas, deg. C:						
Before washing.....	144.0	158.0	144.0	46.0	45.0	43.0
After washing.....	30.0	37.0	30.0	33.0	28.0	36.0
Temperature of water, deg. C:						
Before washing.....	14.0	7.0	12.0	28.0	20.0	18.0
After washing.....	39.0	40.0	55.0	37.0	34.0	19.0
Cooling water consumed:						
Cubic feet per hour.	667.0	424.0	360.0	565.0	247.0	360.0
Gal per 1000 cu ft	8.22	7.48	7.48	7.78	7.93	8.45
Volume of gas per hour, cubic feet.....	607,160	423,600	360,060	529,500	211,800	317,700

<sup>1</sup> HOFMAN'S "General Metallurgy."

## STEEL ROLLING

CUBIC MILLIMETERS OF STEEL DISPLACED BY 1 KG.-M. OF ENERGY AT DIFFERENT TEMPERATURES<sup>1</sup>

Square ingots to	At temperatures, deg. C.			
	1300	1200	1000	900
Flats.....	100	45	20	18
Rounds.....	80	50	.....	.....
T-girders.....	85	67	20	10
Rails.....	.....	70	20	.....

<sup>1</sup> HOFMAN'S "General Metallurgy," p. 665.

## Shrinkage of Castings per Foot

Cast iron.....	$\frac{1}{8}$ in.	Zinc.....	$\frac{5}{16}$ in.
Brass.....	$\frac{3}{16}$ in.	Tin.....	$\frac{1}{12}$ in.
Steel.....	$\frac{1}{4}$ in.	Aluminum.....	$\frac{3}{16}$ in.
Malleable iron.....	$\frac{1}{8}$ in.	Britannia.....	$\frac{3}{32}$ in.

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## LINEAR CONTRACTION OF ALUMINUM ALLOYS

Analysis	Per cent. contraction	Analysis	Per cent. contraction
92:8 Al:Mg . . . . .	1.15	90:8:2 Al:Cu:Mg . . .	1.08
92:8 Al:Cu . . . . .	1.34	90:8:2 Al:Cu:Si . . .	1.17
92:8 Al:Sn . . . . .	1.38	90:8:2 Al:Cu:Ni . . .	1.25
92:8 Al:Ni . . . . .	1.42	90:8:2 Al:Cu:Sn . . .	1.26
No. 12 alloy . . . . .	1.50	90:8:2 Al:Cu:Fe . . .	1.29
.....	.....	90:8:2 Al:Cu:Zn . . .	1.29
No. 31 alloy . . . . .	1.50	90:8:2 Al:Cu:Mn . . .	1.40

## LINEAR CONTRACTION; ALLOYS OF COPPER

Nominal composition	Pouring temp., deg. F.	Linear contraction, per cent. high and low pouring temp.
56:40:1:1.5:1.5 Cu:Zn:Fe:Al:Mn . .	1900	2.17-2.19
60:40 Cu:Zn . . . . .	1900	1.80-1.89
70:30 Cu:Zn . . . . .	2000	1.75-1.77
60:38:2 Cu:Zn:Sn . . . . .	1900	1.69-1.875
70:29:1 Cu:Zn:Sn . . . . .	1950	1.65-1.67
86:4:6:3:1 Cu:Ni:Sn:Zn:Pb . . . . .	2300	1.43-1.425
85:5:5:5 Cu:Sn:Zn:Pb . . . . .	2300	1.425-1.47
87:7:5:1 Cu:Sn:Zn:Pb . . . . .	2250	1.40-
80:20 Cu:Sn . . . . .	2200	1.375-1.55
76:7:4:13 Cu:Sn:Zn:Pb . . . . .	2300	1.37-1.37
88:10:2 Cu:Sn:Zn . . . . .	2350	1.33-1.30
88:8:4 Cu:Sn:Zn . . . . .	2300	1.33-
86:11:3 Cu:Sn:Zn . . . . .	2300	1.33-1.39
90:6:3:1 Cu:Sn:Zn:Pb . . . . .	2300	1.33-1.43
84:10:5:1 Cu:Sn:Zn:Pb . . . . .	2300	1.32-1.35
84:11:5 Cu:Sn:Zn . . . . .	2300	1.32-1.36
85:15 Cu:Sn . . . . .	2300	1.31-1.45
89:8:10:0.2 Cu:Sn:P . . . . .	2400	1.275-1.28
90:10 Cu:Sn . . . . .	2400	1.275-1.30
89:5:10:0.5 Cu:Sn:P . . . . .	2400	1.26-
80:10:10 Cu:Sn:Pb . . . . .	2300	1.25-1.31

## LINEAR CONTRACTION; PURE METALS

Aluminum . . . . .	1.75
Gray iron . . . . .	1.00
Steel . . . . .	2.01

Molding-sand Tests<sup>1</sup>

**Test for "Grain," or Fineness.**—A sample of dried sand is shaken 1 hr. in a  $\frac{1}{20}$  per cent. NaOH solution to deflocculate the clay or bonding substance contained on the grains. Washing is done by shaking the sand with fresh water, settling for 5 min. and siphoning off the liquid from a point 2.5 cm. from the residue, repeating the operation until the wash water is clear. The residue is filtered under suction, dried 30 min. at 105°C. and then screen-sized for 15 min. in a "Ro-tap" machine. In this way amounts of sand remaining on 6, 12, 20, 40, 70, 100, 140, 200 and 270 screens may be weighed; the results are best expressed by plotting weight of the fractions against the size of sieve opening.

**Permeability.**—This property permits the passage of gases and allows the mold to properly "vent." Consequently, the test measures the flow of air through a standard sample. First dry the sand carefully, and then mix with a measured quantity of water. This may be done on a plate inclosed in a little tent made of moist muslin. Screen twice and store in an airtight jar while checking the moisture content. A tolerance of  $\pm 0.2$  per cent. is permissible. Sufficient sand is then placed in a 2-in. brass cylinder to make a briquet  $2 \pm 0.08$  in. high after being rammed three times by a 14-lb. weight dropping 2 in. This briquet is then placed in a container, and air forced through it. A recommended form of apparatus consists essentially of a calibrated vessel from which air is displaced by water flowing in from a reservoir under a constant head of  $22\frac{1}{2}$  in. Air so expelled passes through the sand sample, and the resistance to this flow sets up a pressure in the exit tube which is measured by a simple manometer. A stop watch measures the time required to pass each liter of air.

$$\text{Permeability} = \frac{\text{air passed} \times \text{height of specimen}}{\text{pressure} \times \text{area of specimen}} \times \frac{60}{\text{time}}.$$

(All measurements in c.g.s. units.) The committee recommends that 2 liters of air be forced through; and with the standard specimen the equation becomes

$$\text{Permeability} = \frac{30,070}{\text{pressure} \times \text{seconds}}.$$

In addition to these three simple tests, an auxiliary test is suggested as desirable. It is called the dye adsorption test, and is a measure of the quality of clayey material present in the sand. In general these materials are hydrated silicates in the colloidal condition; a considerable quantity is usually associated with a sand of strong bonding qualities. To execute the test, a given weight of sand is shaken with water and alkali, and the suspended material removed by siphon or decantation. A measured amount of crystal violet is then added to the liquor and the resulting color compared against standard solutions; 1,200 to 1,500 mg. of dye will be adsorbed by the colloids in

<sup>1</sup> Recommended by the American Foundrymen's Association.

100 grams of sand if it has a strong bond; weak bonds adsorb as little as 200 mg.

**Inhibitors.**—Certain organic compounds added to pickling acids used on steel greatly cut down the acid used and the steel dissolved. Particularly effective are bases containing nitrogen, such as analine; pyridine,  $C_5H_5N$ ; quinoline,  $C_9H_7N$ ; and the like. The concentration of the inhibitor is small. Quinoline ethiodide is effective in concentrations of 0.01–0.1 per cent.

**Screen Analysis of Ores.**—In considering the advisability of briquetting or sintering any given ore, the point brought up by A. N. DIEHL (Am. Iron & Steel Inst., May, 1915) should be considered. This is, that the ordinary screen analysis of dry ore is misleading, as fine particles cling to the larger ones. He therefore gives it as his opinion that wet sieving tests should be used, as in these the fine particles are washed through the screens and one obtains a better classification. He gives some comparative tests as follows:

#### COMPARISON OF DRY AND WET ANALYSIS OF ORES

	Ore No. 1, per cent.		Ore No. 2, per cent.		Ore No. 3, per cent.	
	Dry	Wet	Dry	Wet	Dry	Wet
On 20-mesh screen . . . . .	54.59	46.40	61.13	46.00	71.08	57.70
On 40-mesh screen . . . . .	10.36	13.80	10.08	8.40	6.92	10.20
On 60-mesh screen . . . . .	12.44	3.30	10.58	3.60	6.29	2.90
On 80-mesh screen . . . . .	1.70	5.80	1.44	4.40	1.25	3.30
On 100-mesh screen . . . . .	4.67	1.10	3.33	0.70	2.51	0.80
Through 100-mesh screen . . . . .	16.24	29.60	13.44	36.90	11.95	25.10
	100.00	100.00	100.00	100.00	100.00	100.00

#### Types of Electric Furnaces

Electric furnaces may be divided into three classes: (1) Arc; (2) resistance; (3) induction furnaces, according to the different methods of applying the heat.

In the arc furnaces the heating is produced by radiation or conduction from an electric arc. This arc is formed by the passage of an electric current at 50 to 120 volts across the air gap between two carbon electrodes, or between one or more carbon electrodes and the surface of the molten metal, which then acts as the second pole of an electric circuit.

In resistance furnaces the heat effect is produced within the metal itself by the resistance offered to the passage of the current through it. The temperature attained by this method of heating cannot equal that attained in arc heating; the radiation and conditioned losses are lower and the thermal efficiency of the furnace is higher.

Induction furnaces form really a subdivision of the resistance type of furnace, since the thermal effect is again due to the



resistance of the metal to the flow of current through it. In this case, however, induced currents of electricity are used in place of direct current. The induction furnace is in fact nothing but a great step-down transformer in which a ring of molten metal forms the secondary circuit and becomes the focus of current of large intensity but low e.m.f. The disadvantages of this type of furnace are its comparatively low temperature and the necessity for retaining a certain proportion at every melt in the annular ring in order to carry the current for melting the next charge. A great advantage is that electrodes are dispensed with and that this costly item of running charges is wiped out. A secondary advantage is that the capital expenditure upon cables and conductors is greatly reduced.

The chief commercial types of furnace fall into the classes as follows: (1) arc—CHAPLET, GRÖNWALL, GIROD, HEROULT, KELLER, NATHUSIUS, SNYDER, STASSANO; arc and resistance—HÄRDEN, NAU, SODERBERG, STOBIE; resistance—QUENEAU (pinch effect), HERING (pinch effect); induction—ANDERSON, COLBY, FRICK, HIORTH, KJELLIN, ROCHLING-RODENHAUSER, AJAX NORTHRUP.

#### Composition of the Silicides and Carbides<sup>1</sup>

$\text{Ni}_2\text{Si}$ ,  $\text{Co}_2\text{Si}$ ,  $\text{Cr}_2\text{Si}$ ,  $\text{Mn}_2\text{Si}$ ,  $\text{Cu}_2\text{Si}$ ,  $\text{Fe}_2\text{Si}$ ,<sup>2</sup>  $\text{Fe}_2\text{Si}$ ,<sup>2</sup>  $\text{W}_2\text{Si}_3$ .

2(a) | 3(b) | 4(c) | 5(f) | 6(d) | 7(f) | 8(f) | 9(e) | 10(f)

$\text{Li}_2\text{C}_2$ ...	$\text{CaC}_2$	$\text{CeC}_2$	$\text{U}_2\text{C}_3$	$\text{WC}$	$\text{Al}_4\text{C}_3$	$\text{Cr}_3\text{C}_2$	$\text{MoC}$	$\text{Mn}_2\text{C}$	$\text{Cr}_3\text{C}$
	$\text{SrC}_2$	$\text{LaC}_2$			$\text{Be}_4\text{C}_3$		$\text{W}_2\text{C}$	$\text{Fe}_3\text{C}$	
	$\text{BaC}_2$	$\text{YtC}_2$							
		$\text{ThC}_2$							

(a) All carbides of this group give acetylene when decomposed with water. (b) These carbides give off complex mixtures of acetylene, ethylene, methane and hydrogen, according to temperature employed. (c) This carbide when decomposed with water gives gases rich in methane. Only about one-third of the carbon is given off in this way, the remainder forms liquid and solid hydrocarbons and carbohydrates. (d) These carbides and water give methane only. (e) Manganese carbide and water give equal mixtures of methane and hydrogen. Iron carbide is not decomposed. (f) These carbides are not decomposed by water.

<sup>1</sup> From Borchers's "Electric Smelting and Refining."

<sup>2</sup> These silicides mix with silicon in all proportions.

**Volatilization of Carbides.**—According to W. R. MOTT (*Journ. Am. Electrochem. Soc.*, Vol. 34, 1918) carbides volatilize in the following order:  $\text{Cr}_3\text{C}_2$ , 3800°C.;  $\text{V}_2\text{C}_3$ , 3900°C.;  $\text{V}_3\text{C}_2$ , 3900°C.;  $\text{U}_3\text{C}_2$ , 4100°C.;  $\text{TiC}_2$ , 4300°C.;  $\text{Ch}_2\text{C}_3$ , 4300°C.;  $\text{MoC}_2$ , 4500°C.;  $\text{Yt}_2\text{C}_3$ , 4600°C.;  $\text{Th}_2\text{C}_3$ , 5000°C.;  $\text{Zr}_2\text{C}_3$ , 5100°C.;  $\text{TaC}_2$ , 5500°C.;  $\text{WC}$  6000°C. (These values appear high—Editor.)

The silicides of W, Mo, Zr, and Th can be formed at temperatures below the melting points of the elements by heating suitable mixtures in a tube from which air has been exhausted. For example Mo and Si combine when so heated in atomic proportions to a temperature of 1100°-1200°. The melting points of Si and Mo are about 1900° and 2100°, respectively.

## 810 METALLURGISTS AND CHEMISTS' HANDBOOK

Beryllium nitride may be prepared by passing cyanogen over metallic beryllium heated at 800°C. A general method of preparation is by partial oxidation of a metallic cyanide. Such a result may be obtained by heating with ammonium nitrate.

### Electric Steel Furnaces<sup>1</sup>

#### POWER CONSUMPTION IN KILOWATT-HOURS PER METRIC TON OF STEEL PRODUCED

	Cold charges composed of			Molten charges from				
	Scrap	Pig iron and Wal-loon iron	Average	Bessemer	Wellman open hearth	Martin open hearth	Cupola	Average for molten charges
Heroult. ....	459	.....	.....	104	.....	.....	.....	.....
	528	.....	493	33	200	.....	.....	146
Girod. ....	750	.....	.....	.....	200	.....	.....	.....
	850	.....	800	.....	275	.....	.....	237
Stassano. ....	918	.....	.....	.....	.....	.....	.....	.....
	958	.....	.....	.....	.....	.....	.....	.....
	1000	.....	.....	.....	.....	.....	.....	.....
	1250	.....	.....	.....	.....	.....	.....	.....
	1260	.....	1071	.....	.....	.....	.....	.....
Röchling- Rodenhauser	640	.....	.....	125	.....	.....	.....	.....
	780	.....	.....	150	280	.....	280	.....
	900	.....	773	200	.....	.....	.....	.....
Frick. ....	780	.....	.....	250	.....	.....	.....	214
	800	.....	790	.....	.....	.....	.....	.....
Keller. ....	.....	.....	.....	.....	.....	275	.....	275
Hiorth. ....	.....	680	.....	.....	.....	.....	.....	.....
	.....	720	.....	.....	.....	.....	.....	.....
	.....	790	730	.....	.....	.....	.....	.....
Colby. ....	605	.....	.....	.....	.....	.....	.....	.....
	825	.....	715	.....	.....	.....	.....	.....
Kjellin. ....	650	.....	.....	.....	.....	.....	.....	.....
	790	.....	.....	.....	.....	.....	.....	.....
	800	.....	747	.....	.....	.....	.....	.....

#### Power Consumption in Ferro-chrome Making<sup>2</sup>

The power consumption in a ferro-chrome furnace of the Meraker Electric Smelting Co., at Kopperaaen, Norway, was recently given as 3 kw-hours per pound, or 0.68 kw.-year per short ton in making a ferro-chrome containing 5 per cent. carbon. At Kanawha Falls, W. Va., ferro-chrome was made in a crucible electric-arc furnace with a power expenditure of 3.6

<sup>1</sup> JOHN B. KERSHAW, "Electrothermal Methods of Iron and Steel Production."

<sup>2</sup> *Iron Trade Review*, May 13, 1915.

kw.-hours per pound, or 0.72 kw.-year per ton. This product contained 70.96 per cent. chromium, 23.23 per cent. iron, 5.21 per cent. carbon, 0.5 per cent. silicon, 0.008 per cent. phosphorus, and 0.078 per cent. sulphur. At both Kopperaen and Kanawha Falls an ore containing about 50 per cent.  $\text{Cr}_2\text{O}_3$  was used.

**Inductive Heating.**—Ajax-Northrup furnace. A conducting helix surrounds the metallic mass to be melted. A high frequency current is passed through the helix. Electromagnetic magnetic energy enters the mass by induction. The helix itself is cooled by water coils. An alloy 46 Fe, 46 Ni, and 8 Cu and Mn was melted in 22 min., using energy at the rate of 566 kw.-hr. per metric ton melted. Furnace efficiency, 82.67 per cent. Nichrome was melted in the same time, using 597 kw.-hr. per metric ton. Both tests were started using a cold crucible.

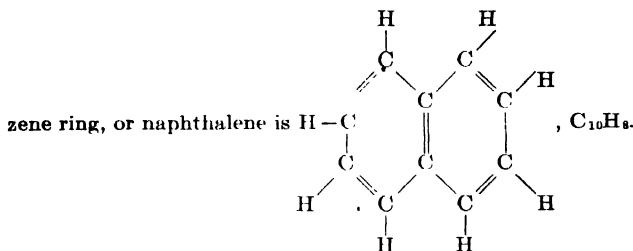
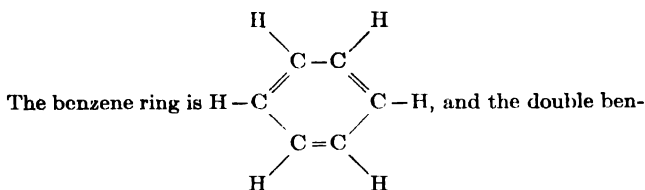
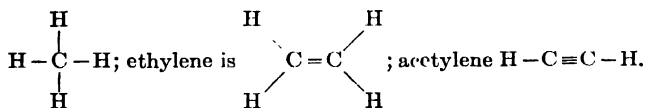
In the June, 1921, issue of the *General Electric Review*, JOHN A. SEEDE gives a table of the kilowatt-hours required in the electrochemical production of various materials, from which the following table is taken:

Material	Kw.-hr per ton
Aluminum.....	30,000
Alundum.....	2,000
Barium oxide.....	1,200
Cadmium.....	2,500
Calcium carbide.....	4,000
Calcium cyanamide.....	3,750
Carbon bisulphide.....	850
Carborundum.....	8,500
Caustic soda, 2,000 lb.	} 3,000
Chlorine, 1,760 lb.	
Copper (electrolytic refining).....	300
Copper (electrolytic deposition).....	2,600
Ferrochromium (60 per cent.).....	8,000
Ferromanganese (76 per cent.).....	5,000
Ferromolybdenum (60 per cent.).....	8,400
Ferrosilicon (50 per cent.).....	5,000
Ferrosilicon (75 per cent.).....	10,000
Ferrotungsten (70 per cent.).....	7,600
Ferrouanium (40 per cent.).....	8,000
Ferrovanadium (35 per cent.).....	6,800
Graphite.....	7,800
Iron (electrothermic).....	2,500
Iron (electrolytic).....	4,000
Lead.....	145
Magnesium.....	27,000
Nitric acid.....	17,500
Phosphorus.....	12,000
Potassium chlorate.....	1,350
Sodium.....	20,000
Sodium chlorate.....	7,000
Tin.....	175
Zinc.....	4,000

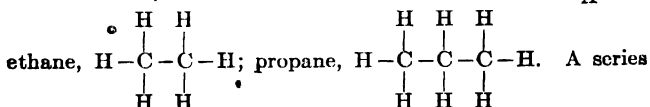
## SECTION XI

### ORGANIC CHEMISTRY

The object of this section is to serve only as a reminder of simplest formulas and properties of the more common organic compounds. Carbon differs from the other elements, except perhaps silicon, in its ability to form highly complex molecules, carbon being linked to carbon, and also in the readiness with which several of its valences will be satisfied by another carbon atom. Thus, the structural formula of methane, marsh gas, is



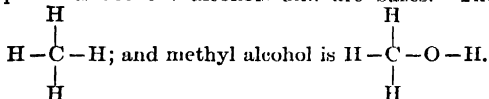
A series, such as the marsh gas series, is methane,  $\begin{array}{c} \text{H} \\ | \\ \text{H}-\text{C}-\text{H} \\ | \\ \text{H} \end{array}$ ;



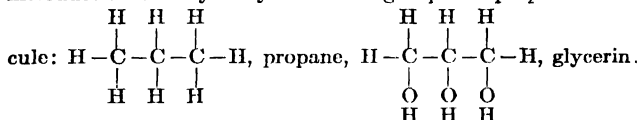
of such compounds is said to be homologous, and the compounds are homologues. As will be seen, each of the above compounds corresponds to the formula  $C_nH_{2n+2}$  (paraffin series); the olefines correspond to  $C_nH_{2n}$ ; the acetylene series to  $C_nH_{2n-2}$ ; the benzene series to  $C_nH_{2n-6}$ , etc.

### Alcohols

In general the first step in the oxidation of a hydrocarbon is the formation of a hydroxyl group replacing a hydrogen. These products are the alcohols and are bases. Thus methane is



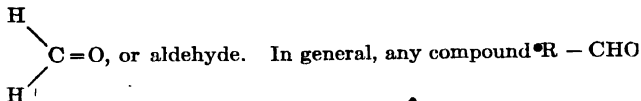
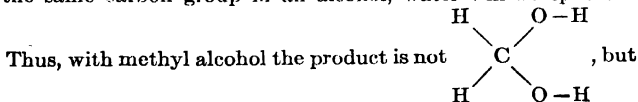
Alcohols may be polybasic. Thus the common compound glycerin in the simplest tri-basic alcohol and is formed by the introduction of a hydroxyl into each group of a propane mole-



In regard to this same compound, propane, it will be noticed that while the compounds  $\text{CH}_3\cdot\text{CHOH}\cdot\text{CH}_3$ , and  $\text{CH}_3\cdot\text{CH}_2\cdot\text{CH}_2\cdot\text{OH}$  are both alcohols of the same number of carbon, hydrogen, and oxygen atoms, their structural formulas are unlike, and their properties differ in some degree. Such compounds are known as metameric. When the percentage composition is the same they are isomeric, the latter including the former class. In general it may be said that after leaving the simpler compounds, a mere knowledge of the number of atoms of carbon, hydrogen, oxygen, etc., in an organic compound is no guide whatever to its properties.

### Aldehydes

If the attempt be made to substitute a second hydroxyl in the same carbon group in an alcohol, water will be split off.



will be an aldehyde with the characteristics of these compounds. pleasant odor, great reducing power, etc.

(Continued on p. 818)

A TABLE OF COMMON

	Formula	Structure <sup>†</sup>	Solubility	
			Water, 20°C.	Water, 100°C.
<b>Hydrocarbons</b>				
Methane	CH <sub>4</sub>	All hydrogens symmetri- cal.	0.003:100	i
Ethane	C <sub>2</sub> H <sub>6</sub>	H <sub>3</sub> C—CH <sub>3</sub>	0.006:100	i
Propane	C <sub>3</sub> H <sub>8</sub>	H <sub>3</sub> C—CH <sub>2</sub> —CH <sub>3</sub>		
Butane	C <sub>4</sub> H <sub>10</sub>	H <sub>3</sub> C—CH <sub>2</sub> ·CH <sub>2</sub> —CH <sub>3</sub>	2:100 vols	i
Pentane	C <sub>5</sub> H <sub>12</sub>	H <sub>3</sub> C—CH <sub>2</sub> ·CH <sub>2</sub> ·CH <sub>2</sub> — CH <sub>3</sub>		
Hexane	C <sub>6</sub> H <sub>14</sub>	CH <sub>3</sub> —CH <sub>2</sub> —CH <sub>2</sub> — CH <sub>2</sub> —CH <sub>2</sub> —CH <sub>3</sub>		
Ethylene	C <sub>2</sub> H <sub>4</sub>	CH <sub>2</sub> =CH <sub>2</sub>	0.015:100	i
Propylene	C <sub>3</sub> H <sub>6</sub>	CH <sub>3</sub> —CH=CH <sub>2</sub>	0.04:100	i
Butylene	C <sub>4</sub> H <sub>8</sub>	CH <sub>3</sub> —CH=CH—CH <sub>3</sub>		
Amylene, β	C <sub>5</sub> H <sub>10</sub>	CH <sub>2</sub> =CH—CH—CH <sub>2</sub> — —CH <sub>3</sub>		
Acetylene	C <sub>2</sub> H <sub>2</sub>	CH≡CH	0.12:100	i
Allylene	C <sub>3</sub> H <sub>4</sub>	CH <sub>2</sub> —C≡CH		
Ethylacetylene	C <sub>4</sub> H <sub>6</sub>	CH <sub>3</sub> —CH <sub>2</sub> —C≡H		
Benzene....	C <sub>6</sub> H <sub>6</sub>	The benzene ring.	0.07:100	
Toluene	C <sub>7</sub> H <sub>8</sub>	CH <sub>3</sub> —C <sub>6</sub> H <sub>5</sub>		
Xylene....	C <sub>8</sub> H <sub>10</sub>	CH <sub>3</sub> —C <sub>6</sub> H <sub>4</sub> —CH <sub>3</sub>		
Naphthalene	C <sub>10</sub> H <sub>8</sub>	The double benzene ring.		
Anthracene.	C <sub>14</sub> H <sub>10</sub>	The triple benzene ring.		
Terpene	C <sub>10</sub> H <sub>16</sub>	Several compounds exist		
<b>Amines</b>				
Methyl-amine	CH <sub>5</sub> N	H <sub>2</sub> =N·CH <sub>3</sub>		
Dimethyl-amine	C <sub>2</sub> H <sub>7</sub> N	H—N=(CH <sub>3</sub> ) <sub>2</sub>		
Ethyl-amine	C <sub>2</sub> H <sub>7</sub> N	H <sub>2</sub> =N—CH <sub>2</sub> —CH <sub>3</sub>		
Hydrazine	N <sub>2</sub> H <sub>4</sub>	H <sub>2</sub> =N—N=H <sub>2</sub>		
<b>Alcohols</b>				
Methyl alcohol	CH <sub>4</sub> O	CH <sub>3</sub> ·OH	∞	∞
Ethyl alcohol	C <sub>2</sub> H <sub>6</sub> O	CH <sub>3</sub> ·CH <sub>2</sub> ·OH	∞	∞
Propyl alcohol	C <sub>3</sub> H <sub>8</sub> O	CH <sub>3</sub> ·CH <sub>2</sub> ·CH <sub>2</sub> ·OH		
Butyl alcohol	C <sub>4</sub> H <sub>10</sub> O	CH <sub>3</sub> ·CH <sub>2</sub> ·CH <sub>2</sub> ·CH <sub>2</sub> ·OH	22.5:100	20:100
Amyl alcohol	C <sub>5</sub> H <sub>12</sub> O	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>3</sub> CH <sub>2</sub> OH	6:100	2:100
Allyl alcohol	C <sub>3</sub> H <sub>6</sub> O	CH <sub>2</sub> =CH—CH <sub>2</sub> OH		
Glycerin	C <sub>3</sub> H <sub>8</sub> O <sub>3</sub>	CH <sub>2</sub> OH·CHOH·CH <sub>2</sub> OH		
Pyrogallol	C <sub>6</sub> H <sub>6</sub> O <sub>3</sub>	C <sub>6</sub> H <sub>3</sub> (OH) <sub>3</sub>	62:100	v s
Phenol	C <sub>6</sub> H <sub>6</sub> O	C <sub>6</sub> H <sub>5</sub> OH	8.3:100	33 at 68°
<b>Aldehydes</b>				
Formic aldehyde	CH <sub>2</sub> O	H <sub>2</sub> =C=O	v.s.	v s
Acetic aldehyde	C <sub>2</sub> H <sub>4</sub> O	CH <sub>3</sub> ·CHO		
Paraldehyde	(C <sub>2</sub> H <sub>4</sub> O) <sub>3</sub>		12.5:100	6.6:100

# ORGANIC CHEMISTRY

## ORGANIC COMPOUNDS

Alcohol	Melting point, °C.	Boiling point, °C.	Specific gravity	
.....	-184	-161.4	0.415 at -164°	Commonly known as marsh gas or fire damp.
.....	-172.0	-88.3	.....	Easily formed by electrolyzing acetic acid.
.....	-189.9	-44.5	0.59 at -45°	The properties are those of the normal butane.
.....	-135.0	-0.6	0.600 at 0°	
.....	-131.5	36.2	0.63 at 17°	There are three pentanes theoretically possible
.....	-94.3	69	0.675 at 17°	Five hexanes are theoretically possible.
.....	-169.4	-105	.....	Prepared by heating ethyl alcohol and H <sub>2</sub> SO <sub>4</sub> to 175°C.
.....	-185.2	-47.0	.....	Commercially prepared from calcium carbide.
.....	.....	1.4	0.739 at 0°	
.....	-139.0	36.4	0.652 at 17°	
.....	-81.8	-83.6	.....	
.....	-104.7	-27.5	.....	The constants are those of the orthoxylene.
.....	-130	18.5	0.668	
.....	5.4	80	0.88 at 15°	
.....	-98	112	0.87 at 18°	
.....	-54	-140	0.86 at 18°	The properties are those of terpene derived from amber.
9 8:100	80	218	1.15 at 20°	
0 08:100	213	251	1.147	
.....	.....	165	0.86 at 20°	
.....	-92.5	-6.5	.....	A stronger base than ammonia.
.....	-96.0	7.4	0.697	
.....	-80.6	16.6	0.696 at 8°	
.....	1.4	.....	1.011 at 15°	
∞	-97.8	64.5	0.796 at 20°	Wood alcohol. Usually prepared by destructive distillation of wood.
∞	-117.3	78.4	0.800 at 20°	Grain alcohol. Usually prepared by fermentation of grain.
.....	-127	97.8	0.805 at 20°	Found in small amount in fusel oil.
.....	-89.8	117.7	0.817 at 20°	There are three butyl alcohols possible.
.....	-78.5	137.9	0.81 at 20°	Found in fusel oil. Eight alcohols are possible.
.....	-129.0	96.6	0.85 at 20°	Formed by heating glycerin with oxalic acid.
.....	17.9	290	1.26 at 20°	The simplest tri-basic alcohol.
100:100	134	309	1.45 at 20°	Found as an ester in tallow, palm oil, etc
.....	41.1	181.4	1.06 at 20°	Prepared by the dry distillation of gallic acid.
.....	-92	-21	0.81 at -21°	Usually known as carbolic acid, but really an alcohol.
.....	-123.5	20.2	0.790 at 18°	Formalin, formaldehyde.
.....	.....	.....	0.995 at 20°	A powerful reducing agent. Polymerizes readily to paraldehyde.
.....	.....	.....	.....	A powerful reducing agent. Forms spontaneously from acetaldehyde.

A TABLE OF COMMON

	Formula	Structure	Solubility	
			Water, 20°C.	Water, 100°C.
<b>Acids</b>				
Formic acid.....	CH <sub>2</sub> O <sub>2</sub>	H·COOH	∞	∞
Acetic acid . . . . .	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	CH <sub>3</sub> ·COOH	∞	∞
Propionic acid .	C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	C <sub>2</sub> H <sub>5</sub> ·COOH	.....	.....
Butyric acid....	C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	C <sub>3</sub> H <sub>7</sub> ·COOH	22.6	36.3
Valeric acid ..	C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	C <sub>4</sub> H <sub>9</sub> ·COOH	.....	.....
Caproic acid.	C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	C <sub>5</sub> H <sub>11</sub> ·COOH	.....	.....
Caprylic acid ..	C <sub>8</sub> H <sub>16</sub> O <sub>2</sub>	C <sub>7</sub> H <sub>15</sub> ·COOH	.....	.....
Capric acid	C <sub>10</sub> H <sub>20</sub> O <sub>2</sub>	C <sub>9</sub> H <sub>19</sub> ·COOH	.....	.....
Palmitic acid ..	C <sub>16</sub> H <sub>32</sub> O <sub>2</sub>	C <sub>15</sub> H <sub>31</sub> ·COOH	.....	.....
Stearic acid...	C <sub>18</sub> H <sub>36</sub> O <sub>2</sub>	C <sub>17</sub> H <sub>35</sub> ·COOH	.....	.....
Benzoic acid. .	C <sub>7</sub> H <sub>6</sub> O <sub>2</sub>	C <sub>6</sub> H <sub>5</sub> ·COOH	0.29:100	5.88:100
Picric acid.....	C <sub>6</sub> H <sub>3</sub> O <sub>7</sub> N <sub>3</sub>	C <sub>6</sub> H <sub>2</sub> ·OH(NO <sub>2</sub> ) <sub>3</sub>	1.1:100	6.75:100
Oxalic acid ..	(COOH) <sub>2</sub>	HOOC-COOH	8.8:100	70:100
Oxalic acid. ....	(COOH) <sub>2</sub> · 2H <sub>2</sub> O	(HO) <sub>3</sub> C-C≡C-(OH) <sub>3</sub> OH	12.4:100	100:100
Lactic acid.....	C <sub>3</sub> H <sub>6</sub> O <sub>3</sub>	CH <sub>3</sub> -CH \ COOH	v.s.	v.s.
Succinic acid....	C <sub>4</sub> H <sub>6</sub> O <sub>4</sub>	(CH <sub>2</sub> -COOH)- (CO <sub>2</sub> H)	.....	.....
Malic acid.....	C <sub>4</sub> H <sub>6</sub> O <sub>5</sub>	(CHOH-COOH)- (CO <sub>2</sub> H)	v s	v s.
Glycollic acid .	C <sub>2</sub> H <sub>4</sub> O <sub>3</sub>	CH <sub>2</sub> OH·COOH	0.03:100	0.85:100
Citric acid....	C <sub>6</sub> H <sub>8</sub> O <sub>7</sub>	(CH <sub>2</sub> -COOH) <sub>2</sub> - C / OH \ CO <sub>2</sub> H + H <sub>2</sub> O	180:100	250:100
Tartaric acid	C <sub>4</sub> H <sub>6</sub> O <sub>6</sub>	CHOH-COOH   CHOH-COOH	v s	v s.
Tannic acid ..	C <sub>14</sub> H <sub>10</sub> O <sub>9</sub>	.....	.....	.....
Oleic acid. . .	C <sub>18</sub> H <sub>34</sub> O	H        \        H C=C C <sub>9</sub> H <sub>17</sub> /        (CH <sub>2</sub> ) <sub>7</sub> - COOH	.....	.....
Fulminic acid	CNOH	C=N-O-H	.....	.....
Galic acid	C <sub>7</sub> H <sub>6</sub> O <sub>5</sub>	C <sub>6</sub> H <sub>2</sub> (OH) <sub>3</sub> -COOH+ H <sub>2</sub> O	1.1:100	33:100
<b>Halogen Compounds</b>				
Di-iodo-methane	CH <sub>2</sub> I <sub>2</sub>	Substitution product	.....	.....
Chloroform.....	CHCl <sub>3</sub>	Substitution product.	0.71:100	v s
Bromoform.....	CHBr <sub>3</sub>	Substitution product.	.....	.....
Iodoform.....	CHI <sub>3</sub>	Substitution product.	0.01:100	v.s.
Chloral .....	C <sub>2</sub> HOCl <sub>3</sub>	CCl <sub>3</sub> ·CHO	See note	.....
Carbon tetrachloride	CCl <sub>4</sub>	Substitution product.	0.08:100	.....



ORGANIC COMPOUNDS. *Continued*

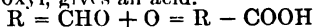
Alcohol	Melting point, °C.	Boiling point, °C.	Specific gravity	
	8.6	100.6	1.22 at 0°	So called as it may be distilled from ants. A strong acid. Produced by the oxidation of alcohol, or the distillation of wood.
	16.5	113	1.06 at 0°	
	-23	140.9	996 at 0°	Found in butter as the glycerol ester.
	-3.1	162.5	961 at 0°	
	-18	186	942 at 0°	Found in valerian root. There are four of these alcohols possible.
	-1.5	205	929 at 0°	
	16.5	236	911 at 0°	All these acids have the normal structure.
	31	270		
	62	>270	.....	Found as the glycerol ester in palm oil.
	69.2	>290	1.00 at 0°	Found as the glycerol ester in tallow.
54.100	121.4	249	.....	Can be sublimed from gum benzoin.
26:100	189		2.00 at 9°	The strongest organic acid.
39:100	.....		1.63 at 9°	
	Decomp	Decomp	1.24 at 15°	Produced by fermentation of milk.
	133	150	1.53 at 9°	Found in amber.
	.....	Decomp 120	1.56 at 4°	Found in apples, cherries, etc.
	80	Decomp	1.20 at 10°	Found in green grapes and in beets.
52.100	153	175	1.55	Found in lemons.
	168		1.76 at 7°	Found in grapes.
	.....		.....	Tannin. Formed artificially by dehydration of gallic acid.
	14	..	1.81 at 19°	Found as its glyceride olein in olive oil, lard, etc.
24:100	Decomp. 220	.....	.....	Fulminate of mercury (CNO) <sub>2</sub> Hg.
.....	2	180	3.32 at 19°	A liquid of high sp. gr. Hence used in laboratory separation of minerals.
	-63	61.2	1.49 at 20°	A powerful germicide of unpleasant odor.
	7.6	151	2.9 at 15°	
1.4.100	119	.....	2.0-3.0	Unites with one molecule of water forming chloral hydrate, which melts at 57°, boils at 97.5°.
1.20.100	.....	98	1.54 at 0°	
.....	22.0	76.7	1.59 at 20°	

A TABLE OF COMMON

	Formula	Structure	Solubility	
			Water, 20°C.	Water, 100°C.
<b>Miscellaneous</b>				
Methyl ether	$C_2H_6O$	$CH_3-O-CH_3$	. . . . .	. . . . .
Sulphuric ether	$C_4H_{10}O$	$CH_3-CH_2-O-CH_2-CH_3$	6.95:100	1 s.
Acetone	$C_3H_6O$	$CH_3\cdot CO\cdot CH_3$	. . . . .	. . . . .
Allyl acetate	$C_5H_8O_2$	$CH_2=CH\cdot CH_2\cdot OOC-\overset{CH_3}{CH_3}$	. . . . .	. . . . .
Amyl acetate	$C_7H_{14}O_2$	$C_5H_{11}\cdot CH_2\cdot COOH$	0.2:100	. . . . .
Cane sugar	$C_{12}H_{22}O_{11}$		v.s.	. . . . .
Glucose	$C_6H_{12}O_6$	$CH_2OH(CHOH)_4\cdot CHO$	v.s.	v.s.
Starch	$(C_6H_{10}O_5)_n$	Very complex molecule.	i	i
Anilin	$C_6H_7N$	$C_6H_5\cdot NH_2$	3.4:100	6.0:100
Cellulose	$(C_6H_{10}O_5)_n$	Very complex molecule.	i	i

*(Continued from p. 813)*

If both groups connected by the  $=CO$  group are hydrocarbon radicals the aldehyde is known as an ketone. Acetone,  $CH_3-CO-CH_3$ , is the simplest. The oxidation of an aldehyde under such conditions as to change the hydrogen of the aldehyde group to a hydroxyl, gives an acid.



The  $-COOH$  group is typical of all organic acids. The simplest are  $H - COOH$ , formic acid;  $H_3 - COOH$ , acetic acid,  $(COOH)_2$  oxalic acid.

ORGANIC COMPOUNDS. *Continued*

Alcohol	Melting point, °C.	Boiling point, °C.	Specific gravity	
.....	.....	-25	.....	
.....	-117.6	34.9	.713 at 18°	
.....	.....	56.5	.792 at 18°	
.....	.....	.....	.928 at 18°	
.....	.....	.....	0.88 at 18°	
.....	.....	.....	1.61	Saccharose
.....	.....	.....	1.38	Grape sugar, starch, starch sugar.
i	.....	.....	1.52	Amylum
.....	-8	184	1.02 at 20°	The base of most coal-tar drugs and dyes. A weak base
i	.....	.....	.....	Insoluble in everything but Schweitzer's reagent.

## Ethers

While the alcohols are hydroxides, the ethers are oxides. The simplest ether is methyl ether  $\text{CH}_3 - \text{O} - \text{CH}_3$ . Methyl ethyl ether is  $\text{CH}_3 - \text{O} - \text{C}_2\text{H}_5$ . Ethyl ether (sulphuric ether) is  $\text{C}_2\text{H}_5 - \text{O} - \text{C}_2\text{H}_5$ . Obviously, hydrogen-methyl ether is a hydroxide, methyl alcohol  $\text{CH}_3 - \text{O} - \text{H}$ .

## SECTION XII

### FIRST AID

#### INSTRUCTIONS FOR FIRST-AID TREATMENT<sup>1</sup>

**Wounds That Bleed—Abrasions, Cuts, Punctures.**—Drop 3 per cent. alcoholic iodine into wound freely; then apply dry sterile gauze to wound and bandage it. Do not otherwise cleanse wound.

**Severe Bleeding.**—Place patient at rest and elevate injured part. Apply sterile gauze pad large enough to allow pressure upon, above and below wound. Bandage tightly.

If severe bleeding continues apply tourniquet between wound and heart and secure doctor's services at once. Use tourniquet with caution and only after other means have failed to stop bleeding.

**Nose Bleeding.**—Maintain patient in upright position with arms elevated. Have him breathe gently through mouth and not blow nose. If bleeding continues freely, press finger firmly on patient's upper lip close to nose or have him snuff diluted white wine vinegar into nose.

**Injuries Which Do Not Bleed—Bruises and Sprains.**—Cover injury with several layers of sterile gauze or cotton, then bandage tightly. Application of heat or cold may help, other means are unnecessary. If injury is severe place patient at rest and elevate injured part until doctor's services are secured.

**Bromine Burns.**—Wash with one volume 25 per cent. ammonia, one volume turpentine, ten volumes 96 per cent. alcohol.

**Bromine or Chlorine Fumes.**—Inhale the vapor from a mixture of turpentine and ethyl alcohol and summon a physician.

**Eye Injuries.**—For ordinary eye irritations flood eye with 4 per cent. boric acid solution. Remove only loose particles which can be brushed off gently with absorbent cotton wrapped around end of toothpick or match.

Do not remove foreign bodies stuck in the eye. In that case and for other eye injuries, drop castor oil freely into eye, apply sterile gauze, bandage loosely and go to doctor.

For oils in the eyes wash with 5 per cent. ethyl alcohol; for alkalis, with 3 per cent. boric acid or 1 per cent. acetic acid; for acids, with 3 per cent. sodium bicarbonate solution. These solutions should be kept on hand.

<sup>1</sup> From a Bulletin of the Conference Board on Safety and Sanitation (National Affiliated Safety Organizations; M. W. ALEXANDER, Secretary, West Lynn, Mass.). Copyright, 1914. Reprinted from *Engineering News*.

For electric flash keep the victim's eyes closed and apply a compress of boracic acid solution\* (1 teaspoonful to a cup of water). Keep eyes closed and the compress on until a physician arrives.

**Fire, Electrical and Sun Burns.**—Do not open blisters. Use burn ointment (3 per cent. bicarbonate of soda in petrolatum) freely on sterile gauze applied directly to burn. Cover with several thicknesses of flannel or soft material, then bandage but not tightly. A 0.5 per cent. solution of picric acid is very good and if neither this nor the soda is available, a paste of flour in water. Lacking this, use a heavy oil, such as machine or transformer oil. On a dry charred burn use only a dry dressing.

**Acid Burns.**—Thoroughly flush wound with water, then dry wound, apply burn ointment and bandage as above. An alternative treatment is to wash with a mixture of seven parts glycerol, one part water and two parts ammonia and then to smear with a salve of ten parts vaseline, one and one-half parts paraffin oil and two parts magnesia. See also p. 827.

**Alkali Burns.**—Thoroughly flush wound with water, then flood with white wine vinegar to neutralize (dilute vinegar for alkaline eye burns), dry wound, apply burn ointment and bandage as above. Another mixture for washing alkali burns is six parts glycerol, three parts water and one part 80 per cent. acetic acid.

**Asphyxiation or Electric Shock.**—See page 824.

**Chills and Cramps.**—Give patient 20 to 30 drops of Jamaica ginger in hot or cold water. If no improvement, send for doctor.

**Cinders in the Eye.**—Roll soft paper up like a lamp lighter and wet the tip to remove, or use a medicine dropper to draw it out. Beware of infecting the eye with a dirty handkerchief corner or similar material. Rub the other eye.

**Dislocations.**—In case of dislocation of finger except second joint of thumb, grasp finger firmly and pull it gently to replace joint, then place finger in splint and bandage. In other cases rest dislocated part and secure doctor.

**Fainting.**—Place flat on back; allow fresh air, and sprinkle with water.

**Fractures.**—Make patient comfortable and secure doctor's services at once. Avoid unnecessary handling to prevent sharp edges of broken bones tearing artery. If patient must be moved, place broken limb in as comfortable position as possible and secure it by splint.

**Frost Bites.**—Rub with ice, snow or cold water, then treat as "fire burns."

**Heat Prostration.**—Give patient teaspoonful of aromatic spirit of ammonia in hot or cold water. In case body feels warm apply cold to it; if necessary give cold bath. In case body feels cold and clammy, apply heat to it and send for doctor.

**Internal Poisoning.**—Immediately secure doctor's services. Make patient drink large quantities of water, preferably warm, and make him vomit by sticking one's finger down his throat or by other means. See "Antidotes," below.

**Lightning.**—Dash cold water over a person struck. See also p. 824.

**Mad Dog Bite.**—If a person is bitten by a dog that has rabies the only reasonable course is to be treated at a Pasteur Institute as soon thereafter as possible. Sucking the wound or cauterization will give a physically clean wound, but is of no avail against the virus of rabies.

**Scalds.**—Cover with cooking soda and lay wet cloths over it. Whites of eggs and olive oil. Olive or linseed oil, plain, or mixed with chalk and whiting. See also "Burns," p. 821.

**Snake Bite.**—Tie cord tight above wound. Open the wound with a knife and suck out the blood at once. A dressing of potassium permanganate may be applied to the wound. Alcohol is useless. Usually a doctor must first treat a case of alcoholism when called in to treat a snake bite.

**Shock, Following Injury.**—In case shock is due to severe bleeding, control it first as directed under "severe bleeding" and summon a doctor.

Lay patient flat on back and keep him warm with blankets, hot-water bottles, etc., and provide plenty of fresh air. Let patient inhale fumes of aromatic spirit of ammonia. If fully conscious give patient hot drink or teaspoonful of aromatic ammonia in hot or cold water.

**Sunstroke.**—Loosen clothing. Get patient into shade, and apply ice-cold water to head.

**Venomous Insect Stings, Etc.**—Apply weak ammonia, oil salt water, or iodine.

## ANTIDOTES FOR POISONS

**First.**—Send for a physician.

**Second.**—Induce vomiting by tickling throat with feather or finger, drinking hot water or strong mustard and water. Swallow sweet oil or whites of eggs.

Acids are antidotes for alkalies, and *vice versa*.

### Special Poisons and Antidotes

Acids.—Muriatic, oxalic, acetic, sulphuric (oil of vitriol), nitric (aqua fortis).	{ Soap-suds, magnesia, lime-water.
Prussic Acid. See p. 823.	{ Ammonia in water. Dash water in face.
Carbolic Acid.	{ Flour and water, mucilaginous drinks. Not a true acid, so alkalies are useless.
Alkalies.—Potash, lye, hartshorn, ammonia.	{ Vinegar or lemon juice in water.
Arsenic.—Rat poison, Paris green.	{ Milk, raw eggs, sweet oil, lime-water, flour and water.

<b>Bug Poison.</b> —Lead, salt-peter, corrosive sublimate, sugar of lead, blue vitriol.	Whites of eggs, or milk in large doses.
<b>Chloroform.</b> —Chloral ether.	Dash cold water on head and chest. Artificial respiration.
<b>Carbonate of Soda.</b> —Copperas, cobalt.	Soap-suds and mucilaginous drinks.
<b>Iodine.</b> —Antimony, tartar emetic.	Starch and water, astringent infusions. Strong tea.
<b>Mercury and its salts.</b>	Whites of eggs, milk, mucilages.
<b>Opium.</b> —Morphine, laudanum, paregoric, soothing powders or syrups.	Strong coffee, hot bath. Keep awake and moving at any cost.

### CYANIDE POISONING

It is recommended that boxes labeled "Antidotes for Cyanide," with directions for use affixed to the lids of the boxes, should be kept in prominent and easily accessible parts of the cyanide plants. Each box should contain: a spoon and a metal receptacle to hold about 1 pt.; one blue hermetically sealed vial containing 30 cc. of 33 per cent. solution of ferrous sulphate; a white vial containing 30 cc. of 5 per cent. caustic-potash solution; and one package, 30 grains, of oxide of magnesium (light). The directions for the use of the antidote should be as follows.

*Preparation of Antidote.*—Quickly empty the contents of the blue vial, of the white vial, and of the magnesia package into the metal receptacle, and stir well with the spoon. This should be done as rapidly as possible, as the patient's chance of life depends on promptness.

*Administration of the Antidote.*—If the patient is conscious, make him swallow the mixture at once and lie down for a few minutes. If the patient is not conscious, place him on his back and pour the mixture down his throat in small quantities, if necessary pinching his nose in order to make him swallow.

*Incite Vomiting.*—After the antidote has been given, try to make the patient vomit by tickling the back of the throat with a feather or with the fingers, or giving a tumblerful of warm water and mustard.

*Then call the undertaker.*

**For cyanide eczema** use equal parts by weight of calomel and bismuth subnitrate and apply locally. It will give immediate relief and will dry up the sores in 2 or 3 days.

Other prescriptions are as follows:

Add 3 oz. of camphor to 1 pt. of olive oil and dissolve by slow heat. This mixture occasions some pain when first applied but will soon afford relief.

In mild cases the following will be beneficial: zinc oxide  $\frac{1}{2}$  oz., zinc carbonate 30 grains, glycerin  $\frac{1}{2}$  oz., lime water to make  $\frac{1}{2}$  pt.

For sores which do not heal use: pure lard 5 oz., olive oil 5 oz., white wax  $2\frac{1}{2}$  oz., spermaceti  $2\frac{1}{2}$  oz., powdered gum benzoin 12 oz.

For selenium poisoning under the fingernails, brush the ends of the fingers with 5 per cent. cocaine solution.

### FIRST AID FOR GAS ASPHYXIATION OR ELECTRIC SHOCK

The U. S. Bureau of Mines recommends the following procedure in rendering first aid to those in need of artificial respiration.

The recommendations apply not only to men who are overcome by electric shock or gases in mines, but also to persons suffering from the effects of illuminating-gas poisoning or from electric shock anywhere. The recommendations are, therefore, of importance to many thousands of workmen:

In case of gas poisoning, remove victim at once from the gaseous atmosphere. Carry him quickly to fresh air and immediately give manual artificial respiration. Do not stop to loosen clothing. Every moment of delay is serious.

In case of electric shock, break electric current instantly. Free the patient from the current with a single quick motion, using any dry non-conductor, such as a newspaper, clothing, rope, or board, to move patient or wire. Beware of using any metal or moist material. Meantime have every effort made to shut off current.

Attend instantly to the victim's breathing. If the victim is not breathing, he should be given manual artificial respiration at once. If the patient is breathing slowly and regularly do not give artificial respiration, but let nature restore breathing unaided.

If patient is unconscious, even if he appears dead, lay him on his belly with arms extended forward, turn his face to one side, remove false teeth, tobacco, etc., from his mouth and draw his tongue forward. This is important, the tongue must be brought forward and held forward.

Kneel, straddling patient's thighs, facing his head, and resting your hands on his lowest ribs. Swing forward and *gradually* bring weight of your body upon your hands and thus upon patient's back, then immediately remove pressure by swinging backward. Repeat this movement about twelve times per minute without interruption for hours if necessary, until breathing has been started and maintained (see illustrations). One's own rate of breathing may be used as a guide to the rapidity of this movement. Artificial respiration should be a trifle slower rather than faster than natural breathing. If natural respiration stops after having once been started, begin again with artificial respiration instantly.



In gas cases, give oxygen. If the patient has been a victim of gas, give him pure oxygen, with manual artificial respiration. The oxygen may be given through a breathing bag from a cylinder having a reducing valve, with connecting tubes and face mask, and with an inspiratory and an expiratory valve, of which the latter communicates directly with the atmosphere.

No mechanical artificial resuscitating device should be used unless one operated by hand that has no suction effect on the lungs. Use the SCHAEFER or prone pressure method of artificial respiration. Begin at once. A moment's delay is serious.



Inspiration; pressure off.



Expiration; pressure on.

Do not give the patient any liquid until he is fully conscious. Give him fresh air, but keep his body warm. Send for the nearest doctor as soon as accident is discovered, advising him what has happened so that he will come prepared. If available, and one has been properly instructed in its use, a hypodermic injection of strychnin or amyl nitrite is good, but these should never be given by anyone untrained in their application.

**Nitrous Acid Poisoning.**—It seems certain that brief exposure to small quantities of nitrous fumes is sufficient to produce serious and fatal poisoning. Air containing enough nitrous fumes to cause a feeling of irritation in the nose or air passages is certainly very dangerous.

The symptoms of poisoning are characteristic, according to Dr. L. G. Irvine (*Med. Journal of South Africa*, Sept., 1915). At the moment of exposure they are slight. There is a sense of irritation in the nose and throat, and of constriction, and perhaps of pain, in the chest. There is headache, smarting of the eyes and coughing. The latter is a characteristic sign.

But these immediate irritant effects may not be severe, and commonly pass off altogether in a short time. The man may feel quite well and may continue to work. He leaves the mine, has his supper perhaps, and goes to his room. Then, in from perhaps four to eight hours afterwards (very rarely later), acute symptoms suddenly come on, and progress with alarming rapidity. In a typical severe case there is marked and increasing distress in breathing, with coughing, and often severe pain in the chest. The cough is at first dry, and auscultation may at this stage reveal no moist sounds. But this condition is speedily followed by the expectoration of a copious frothy rather fluid blood-stained spit. The lungs become waterlogged, and auscultation now reveals copious moist sounds. There is cyanosis and marked dyspnoea and distress, followed, unless the case is promptly treated, and very often in spite of all treatment, by collapse, unconsciousness, and death *within a few hours*.

The typical sequence of symptoms in nitrous fumes poisoning is therefore this: (1) *Initial symptoms* of irritation occurring at the moment of exposure and usually comparatively slight. Nitrous fumes never, in our experience of ordinary gassing accidents, produce partial or complete unconsciousness at the time of exposure, as does carbon monoxide, although they may do so if present in massive amounts, and cases of rapid death from the concentrated fumes of burning explosives may be partly due to this cause. (2) *A latent period of several hours duration*, during which the patient may, and commonly does, feel quite well. (3) *The sudden onset, after that interval, of acute symptoms*, due to a rapidly progressive inflammatory oedema of the lungs. The appearance of this well-marked symptom-sequence is of great diagnostic significance.

From what is said, it seems probable that a number of the deaths of workers in powder plants ascribed to pneumonia are really due to nitrous- and nitric-fume poisoning and greater care in avoiding these gases should be exercised than is ordinarily used.

Where it is believed that dangerous exposure to nitrous acid fumes has occurred, an emetic seems advisable, copper or zinc sulphate being commonly employed, following this by a dose of sal-volatile. A hypodermic of apomorphin may be given to produce the same effect, but this should be given by a physician and either preceded or followed by an injection of strychnin or pituitrin.

**Antidote for Chlorine and Fluorine.**—According to LEON G. HALL the persistent soreness and congestion of the throat and lungs that follows exposure to chlorine or to fluorine is easily preventable. A treatment that the writer has used successfully several times consists in breathing steam containing the vapor of benzoin. To be most effective, this should be done as soon as possible after exposure.

The writer's practice is to heat water in an open pan over a gas plate. When the water has begun to boil 6 to 10 drops of tincture of benzoin are added. While the liquid is kept

boiling the vapors are deeply inhaled for 5 to 10 minutes. Little inconvenience has followed prolonged breathing of as heavy concentrations of these gases as can be repeatedly taken into the lungs, when exposure has been followed by the treatment outlined.

**First Aid Treatment for CO Poisoning.**—1. Administer oxygen as quickly as possible and in as pure a form as is obtainable, preferably from a cylinder of oxygen through an inhalator mask.

2. Remove from atmosphere containing CO.

3. If breathing is feeble, at once start artificial respiration by the prone pressure method.

4. Keep the victim flat, quiet and warm.

5. Afterward give plenty of rest.

**Chemical Burns.**—The Aetna Life Insurance Company points out a number of the treatments that it recommends for immediate application in the case of various chemical burns. The burns are classified according to acid or alkali source, the former including burns from nitric, sulphuric, muriatic, acetic, oxalic, hydrofluoric, picric, carbolic, and chromic acids. The latter are represented by caustic soda and potash, lime, ammonia, and soda ash.

It is suggested that it is always desirable to determine first whether a burn is acid or alkaline. Litmus paper, wet in water should be used. In either case, then, the burn should be well flushed with water after which it is to be neutralized, in case of acid, with 10 per cent. soda solution, and in case of alkali, with weak vinegar (or 2 per cent. acetic acid). The bathing of the spot with the neutralizing solution should continue for some minutes. The dressing to be used after neutralization is identical with that for ordinary burns.

In certain cases, special treatment is recommended. Chromium burns require immediate treatment with sodium hyposulphite solution. Phenol burns should be washed freely with clean water after which alcohol is applied. Prussic acid burns should be bathed freely in hydrogen peroxide after a thorough water flushing.

**Diazo-compound Poisoning.**—The symptoms are an itching rash, with watery blisters in the second stage. Oily and greasy salves aggravate the complaint. Powdered boric acid prevents the spread of the blisters to a large extent. Rubbing the skin before beginning work with a mixture of equal parts of boric acid and talc seems effective.

**Extinguishing Carbon Bisulphide Fires.**—Carbon bisulphide is probably the most hazardous liquid used in manufacturing processes today. It can be ignited when at temperatures as low as 20°F., and when heated to only 300°F. it ignites itself. A fire once started is very difficult to control, the ordinary methods of extinguishing being practically worthless and the choking fumes of sulphur dioxide given off making approach difficult unless there is ample ventilation. Furthermore, the vapors of carbon bisulphide are explosive, so that an addi-

tional serious hazard is present when this liquid is used in a confined space.

Tests to determine the value of various extinguishing agents on fires in this material have been made recently by the Factory Mutual Laboratories. Practical conditions were approximated by igniting carbon bisulphide in open tanks, and attempts were made to put out the fires with various extinguishing agents.

Sawdust and soda mixture, a good extinguisher for fires in most hazardous liquids, was found to be ineffective until enough of the material had been added to absorb all the liquid. Even then vapors continued to pass through a blanket of sawdust and burn.

Carbon tetrachloride did not extinguish the fire even after a quantity equal to the amount of carbon bisulphide had been added. In view of the large amount of carbon tetrachloride which would be required, it is not considered a suitable extinguishing agent, except in enclosed spaces, where the inert atmosphere produced can be maintained.

Foam had little cooling effect, and although it greatly reduced the severity of the fire for a time, it could not be depended upon as a positive extinguishing agent, because vapors of carbon bisulphide penetrated the foam blanket and continued to burn at the surface.

Water from automatic sprinklers or from hose streams is ineffective because of the splashing which takes place. This increases the intensity of the fire and may force the burning liquid over the sides of the tank and so spread it over a large area.

The most effective method was found to be by the use of water allowed to flow quietly into the burning material from a low pressure hose stream, or admitted to the liquid at moderately low pressures through a perforated pipe below the surface. The important thing is to apply the water, which is lighter than carbon bisulphide and does not mix with it, so that no splashing occurs. The water collects on the surface and extinguishes by a blanketing rather than a cooling action, although the cooling action is probably sufficient to lower the temperature below its boiling point.

It is apparent that carbon bisulphide should be used inside main buildings only when absolutely necessary, and then only in small quantities. Processes involving its use should be located in outside detached buildings. Open tanks of the liquid should be equipped with perforated pipes at the bottom, with feed pipes of a diameter small enough so that the water will be delivered at low pressure and will not break the surface of the liquid. The controlling valve should be located in an easily accessible location some distance from the tank.

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